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TRACING THE LIQUID FERTILIZER SPILL IN THE MISSOURI RIVER FROM SIOUX CITY, IOWA, JANUARY 26-FEBRUARY 15, 1966

Herbert C. Clare

Federal Water Pollution Control Administration
Kansas City, Missouri

13 July 1966

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UNITED STATES
DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MISSOURI BASIN REGION
601 East 12th Street
Kansas City, Missouri 64106

July 13, 1966

TO: See attached list

FROM: Acting Regional Director

SUBJECT: Tracing the Liquid Fertilizer Spill in the Missouri River from Sioux City, Iowa, January 26-February 15, 1966

Attached you will find a copy of our report on the above subject. Some of you did not return the copy of the working draft which we sent you with our Memorandum, same subject as above, dated April 27, 1966. It is requested that you discard the preliminary draft and replace it with the attached since there have been a number of important revisions.

Your cooperation and assistance in helping trace this spill in the Missouri River from Sioux City, Iowa, to St. Louis, Missouri, is sincerely appreciated. We are also grateful for your assistance in supplying information and material for this report.

HERBERT C. CLARE, P.E.

Attachment

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Attn: Dr. F. H. Hubbard
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3<

REPORT OF
LIQUID FERTILIZER SPILL INTO THE MISSOURI RIVER AT
SIOUX CITY, IOWA, JANUARY 26, 1966

SUMMARY

1. A fertilizer spill occurred at Sioux City, Iowa, January 26, 1966, at 5:15 a.m. A large tank of 10-34-0 liquid fertilizer broke during extremely cold weather (-10° F.). This break also resulted in ruptures of ammonium hydroxide and molasses tanks.

2. Mr. William Lohry of the Nutra-Flo Chemical Company estimated that the spill into the Floyd River consisted of:

   1,000,000 gallons of 10-34-0 liquid fertilizer
   100 tons of molasses
   50,000 gallons of ammonia water

3. The spill occurred about 1,100 feet above the mouth of the Floyd River. The Floyd River empties into the Missouri River in the southern edge of Sioux City at River Mile 730.5.

4. The following places downstream from the fertilizer spill use water from the Missouri River for municipal water supplies:

Omaha, Nebraska	- River Mile 626.2
Council Bluffs, Iowa	- River Mile 618.9
St. Joseph, Missouri	- River Mile 452.2
Atchison, Kansas	- River Mile 423.0
Leavenworth, Kansas	- River Mile 396.8
Kansas City, Kansas	- River Mile 373.7
Kansas City, Missouri	- River Mile 370.5
Lexington, Missouri	- River Mile 318.0
Glasgow, Missouri	- River Mile 227.0
Boonville, Missouri	- River Mile 197.0
Jefferson City, Missouri	- River Mile 145.0
St. Louis, Missouri	- River Mile 37.0
St. Louis County, Missouri	- River Mile 36.5

5. The ammonium ion caused an increase in chlorine demand in all of the downstream water plants. Some of the plants did not have enough chlorination capacity to reach the break point.

6. The following plants had more taste and odor complaints than normal:

   Omaha, Nebraska
   St. Joseph, Missouri
   Atchison, Kansas
   Kansas City, Kansas
   St. Louis County

   No taste or odor complaints were recorded at Council Bluffs, Iowa; Leavenworth, Kansas; Kansas City, Missouri; Lexington, Missouri; Glasgow, Missouri; Boonville, Missouri; Jefferson City, Missouri; or St. Louis (city), Missouri.

7. At the time of the fertilizer spill it was -10° F. at Sioux City. The River was freezing in many stretches of the stream, resulting in less flow downstream than that at Gavins Point (River Mile 811.1).

8. By the time the fertilizer spill reached the vicinity of Jefferson City, Missouri, the ice had broken up. This, in conjunction with heavy rains in Missouri, resulted in much greater streamflows. The Missouri River streamflows during the passage of the fertilizer spill were approximately 12,000 cubic feet per second at Kansas City and 140,000 cubic feet per second at St. Louis.

9. A total phosphate concentration of 57.5 mg/l as PO_4 was measured in the raw water at Omaha, Nebraska, at 9:00 p.m. on January 27. At 10:00 p.m., the high concentration of ammonia nitrogen was 13.0 mg/l.

10. Some water plant operators, particularly those upstream, reported a drop in pH that accompanied the spill. For example: J. David Hines of the St. Joseph, Missouri, Water Company indicated the pH at his plant dropped from 7.9 to 7.4. At Omaha, Nebraska, Joseph Erdei also reported a pH drop of approximately 0.5, that is, from 8.2 to 7.7.

11. The fertilizer spill resulted in the use of additional chemicals at the following plants, which use break-point chlorination: Omaha, Nebraska; St. Joseph, Missouri; Atchison, Kansas; Leavenworth, Kansas; Kansas City, Kansas; Lexington, Missouri; Glasgow, Missouri; Boonville, Missouri; and St. Louis County.

    Water plants at Council Bluffs, Iowa; Kansas City, Missouri; Jefferson City, Missouri; and St. Louis (city), Missouri, did not report an increase in chemical demand directly attributable to the spill.

12. There were no noticeable effects on water treatment in plants on the Mississippi River downstream from the mouth of the Missouri River.

13. Plant operators and many State people have expressed concern about this and other types of spills that could occur and affect public health or water plant operation. Many feel strongly that there should be regulations requiring controls that would result in much better protection. Dykes such as are used for oil tanks have been suggested. Also, locations with reference to water courses would be a factor.

14. In the past, there have been many instances of spills that have been of concern to water users. Some examples are:

    a. Contamination of the Missouri River at Omaha, Nebraska, by pesticide, May 3, 1965.

    b. Oil spills affecting the Minnesota and Mississippi Rivers, winter 1962-63.

INTRODUCTION

At 11:45 a.m. on January 26, 1966, Mr. Elmo W. McClendon of the Missouri River Division Office, U.S. Army Corps of Engineers, notified the Regional Office of the Federal Water Pollution Control Administration (FWPCA) at Kansas City, Missouri, of a liquid fertilizer spill at the Nutra-Flo Chemical Company storage yard (tank farm) in Sioux City, Iowa.* Shortly thereafter, this office was also notified of the spill by Mr. Joseph F. Erdei, Chief Chemist of the Omaha Metropolitan Utilities District; Mr. Phil Bowen of the Omaha District Office, U.S. Army Corps of Engineers; and Mr. Dave Henry of the Kansas City District Office, U.S. Army Corps of Engineers.

Mr. Paul Houser of the Iowa State Department of Health; Mr. Paul Decker of the Missouri Water Pollution Board; Mr. Lou Garber of the Missouri Division of Health; and Mr. Melville Gray of the Kansas State Department of Health were immediately notified of the spill by the Regional Office, FWPCA.

The following information was taken from a report submitted by Mr. M. L. Thornton of the Iowa State Department of Health:

> An employee of the Nutra-Flo Chemical Company terminal reported that filling of the 1,250,000 gallon liquid fertilizer** tank had been completed on the evening of January 25, 1966. This tank ruptured at 5:15 a.m. on the morning of January 26,*** breaking a spigot from a 760,000 gallon molasses tank to the south and rupturing a 125,000 gallon tank of aqua ammonia to the northwest. The molasses tank contained approximately 256,000 gallons of molasses, but the elevation of the spigot was such that only a portion of the molasses was lost. A tank truckload of the molasses had been loaded from this tank just prior to the spill. The 125,000 gallon aqua ammonia tank was believed to have been full, and all of this was spilled. The aqua ammonia was reported as being 25 percent NH_3 or 20 percent N.
>
> The total spill was estimated as 1,250,000 gallons of 10-34-0, 125,000 gallons of aqua ammonia, and a few hundred gallons of molasses.
>
> The storage tanks involved were welded sheet steel tanks. No structural steel reinforcing members were observed inside or outside of these tanks.

*See sketch, page 5.

**The liquid fertilizer was an aqueous solution of salts of ammonium phosphate with a strength of 10 (10 percent ammonia nitrogen) -34 (34 percent phosphate as P_2O_5) -0 (0 percent potassium).

***The ambient temperature was -10° F.

It appeared that the 10-34-0 tank started tearing at the bottom on the south side and tore upward. The location of this tank and the point at which it split led to the assumption that approximately 50 percent of the 10-34-0 went east to the Floyd River and the other 50 percent west toward Interstate 29. The surface of the interstate highway at this point is approximately the same elevation as the tops of the chemical tanks, which are reportedly 40 feet high.

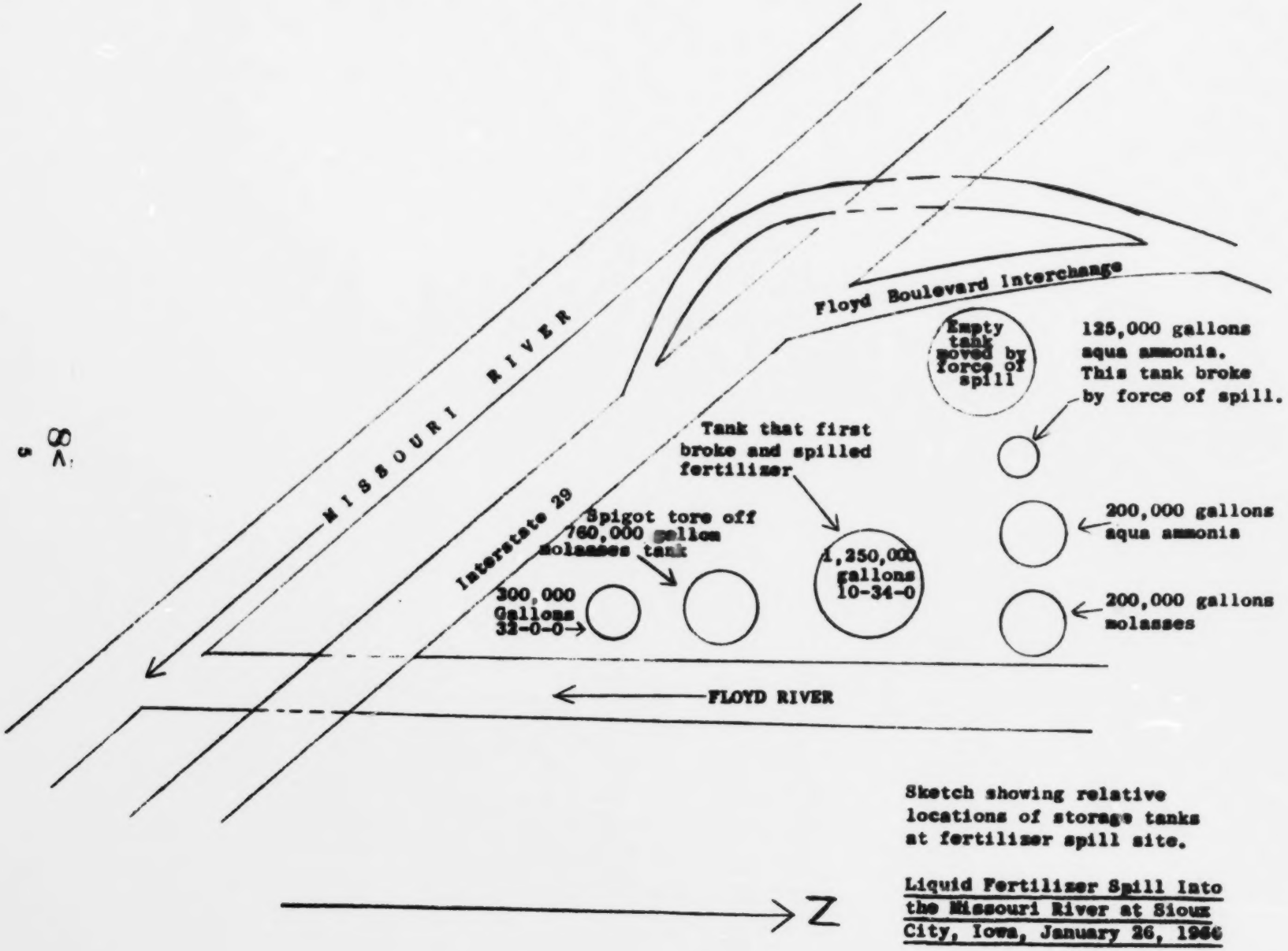
A white material blanketed the area around the 10-34-0 tank and the area to the north and west of this tank. This material varied from a depth of two feet in some places to a trace in others. Employees of the Nutra-Flo Chemical Company were of the opinion that the precipitate resulted from the mixing of the 10-34-0 and the aqua ammonia. (It was probably a mixture of ammonium phosphate salts that crystallized from solution because of the low temperature (-10° F.) and the common ion effect from the ammonium hydroxide. HCC)

The Nutra-Flo Chemical Company was informed by officials of the Iowa State Department of Health that this precipitate should not be placed in the River during clean-up operation. Employees of the Company stated that the precipitate would be hauled away and spread on farm land.

Some molasses was mixed with the white precipitate in spots; but because of the -10° F. temperature at the time, the molasses was very stiff and did not flow readily. It appeared that a very small amount of molasses flowed into the Floyd River.

It was estimated by Iowa State Department of Health officials that approximately two-thirds of the fertilizer eventually reached the Missouri River and the remainder precipitated out. It also appeared that the fertilizer which went east reached the Floyd River almost instantaneously and probably reached the Missouri River within five to ten minutes. The portion which flowed west required considerably more time to reach the Missouri, probably as much as one-half hour.

During the afternoon and evening of January 26, on the occasion of another meeting at Omaha, the spill was discussed with Mr. T. A. Filipi, Director, Environmental Health Services of the Nebraska State Department of Health; Mr. Paul J. Houser, Director, and Mr. R. J. Schliekelman, Public Health Engineer, of the Iowa State Department of Health, Division of Public Health Engineering; Mr. Melville W. Gray, Assistant Director of the Kansas State Department of Health, Environmental Health Services; and Mr. Herbert C. Clare, Regional Program Director, and Mr. Donald A. Townley, Chief, Enforcement Activities of the Regional Office, Federal Water Pollution Control Administration. It was agreed that no hazard or danger to health was expected from the fertilizer spill since ammonium phosphate is a food supplement. Interference with water treatment was discussed, however. This interference was expected to include increased chlorine demand, with perhaps some difficulties in coagulation if meta phosphates were present.


MISSOURI RIVER
Floyd Boulevard Interchange
Empty tank moved by force of spill
125,000 gallons aqua ammonia. This tank broke by force of spill.
Tank that first broke and spilled fertilizer
Interstate 29
Spigot tore off 760,000 gallon molasses tank
1,250,000 gallons 10-34-0
300,000 Gallons 32-0-0
200,000 gallons aqua ammonia
200,000 gallons molasses
FLOYD RIVER
N
Z

Sketch showing relative locations of storage tanks at fertilizer spill site.

Liquid Fertilizer Spill Into the Missouri River at Sioux City, Iowa, January 26, 1966

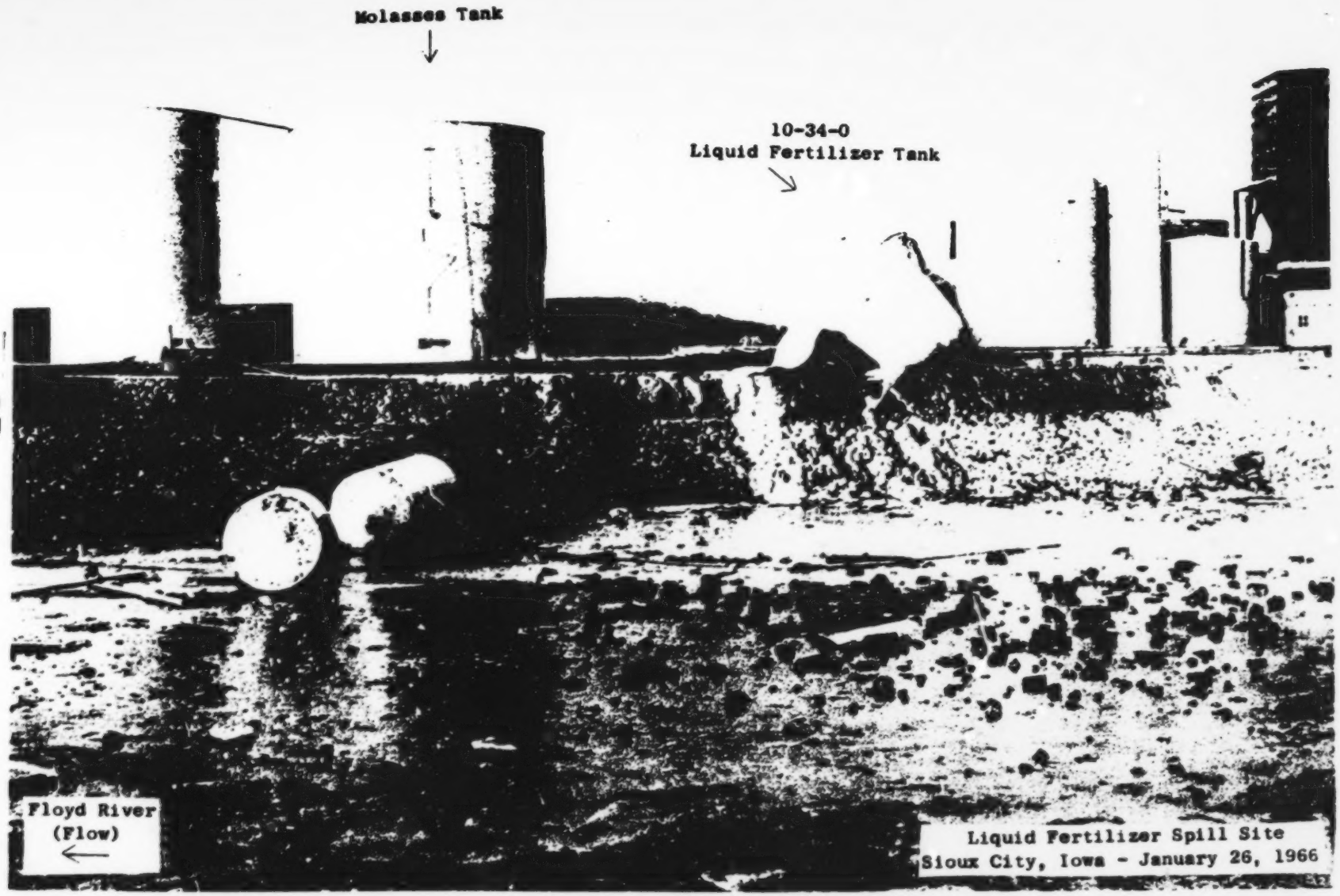


Photo courtesy of the Sioux City Journal.

An attempt was made to determine rates of streamflows by using chemical analyses results at the different points in the Missouri River. The Corps of Engineers "Time of Water Travel" graph* illustrates the time and distance relationships between these points. Ice conditions and gage heights are also shown which indicate changes in the Missouri River during the passage of the fertilizer spill.

Changes in river conditions during the passage of the fertilizer spill plus other variables resulted in some unexpected results. Some of the items that could result in apparent inconsistencies are:

1. The effects of ice and/or ice formation.

2. Sampling in the plant rather than at the river inlet.

3. Changes in streamflows due to breaking ice jams, melting ice, and/or change in stage due to rainfall.

4. Changes in river water quality due to items other than the fertilizer spill.

Changes in ice conditions caused changes in rates of streamflow. When changes of water quality were noted at some point in the plant, estimates of delay in the plant had to be made to determine the approximate time that the spill reached the water intake. Streamflow rates changed due to both ice conditions and rainfall. Rainfall run-off could have carried more than normal concentrations of ammonia and phosphate compounds into the Missouri River.

*See Appendix 3, Exhibit No. 22.

TRACING THE SPILL IN THE MISSOURI RIVER

OMAHA, NEBRASKA (R.M. 626.2)

Based on Corps of Engineers and Weather Bureau estimates of time of flow, it was calculated that the "slug" would arrive at Omaha about noon on January 28. The flow in the Missouri River at Sioux City was 17,000 cfs and at Omaha, 18,000 cfs. Mr. Erdei and FWPCA personnel discussed analyses that should be made and their frequency. Mr. Erdei advised that on January 27, well ahead of the expected time of arrival of the slug, he would check chlorine demand and phosphates and work out a routine for sampling. Actually, the slug arrived at Omaha approximately 24 hours ahead of the time calculated, that is, about 1:45 p.m. on January 27, and reached a peak at about 9:00 p.m. on Thursday, January 27. On the morning of January 28, it was reported that turbidities of raw water at Omaha were high and that coagulation and sedimentation were very poor. Alum dosages of 100 parts per million were used when normally 20 parts per million are adequate. Chlorine demand increased from a normal average of 1.2 to 30 mg/l. All available chlorinators were placed in operation at full capacity. It was not possible to continuously maintain break-point chlorination at Omaha. The pH of the river water dropped from 8.2 at 3:00 p.m. to 7.65 at 8:00 and 9:00 p.m. on January 27. The low pH coincided with the peak concentrations from the fertilizer spill.

There was a slight increase in tastes and odors. It was calculated that the time of travel from Sioux City to Omaha was 40.5 hours. The rate of flow was calculated to be 2.6 miles per hour.

COUNCIL BLUFFS, IOWA (R.M. 618.9)

The fertilizer slug reached Omaha, Nebraska, and Council Bluffs, Iowa, on January 27. Lime and soda ash softening is used at Council Bluffs. The chlorine dosage was not changed as the fertilizer reached Council Bluffs. The chlorine residual stayed about the same, .5 to .8 mg/l, and there were no taste or odor complaints.

ST. JOSEPH, MISSOURI (R.M. 452.2)

It was originally estimated that the spill would arrive at St. Joseph at approximately 8:30 p.m. on January 31. Based on a re-evaluation of time of flow from Sioux City to Omaha, this estimate was revised to a time of arrival at St. Joseph at noon on January 29. At St. Joseph, chlorine is added at a point in the plant about 18 hours in time after the water is pumped from the River.

The water plant operator first noticed an increase in the chlorine demand at 11:00 p.m. on February 1. This means that the time of arrival in St. Joseph was between 5:00 p.m. and 9:00 p.m. January 31. In spite of the fact that St. Joseph raised the chlorine feed from a normal dose of 4.2 to 4.8 mg/l to 5.4 mg/l water, they were able to maintain only a combined

residual. They received a few odor complaints and complaints of dead goldfish. It was reported that the Missouri River was blocked with ice below the water intake. Spot checks for raw water pH indicated a drop in pH from 7.9 to 7.4 - 7.5 during the passing of the fertilizer spill.

At St. Joseph it was reported that there were complaints of sneezing and respiratory problems on the kill floor (where large amounts of water are used) of several meat packing plants. Although the report indicated that "high combined chlorine residuals" might have been the cause, consideration should also be given to the possibility that free ammonia might have been released by alkalies which may have been present.

St. Joseph also reported that although the spill gave Missouri River water treatment plants an opportunity to try out chlorine-ammonia treatment, experience at St. Joseph revealed that this treatment was not nearly as effective for killing bacteria as break-point chlorination. This conclusion is based on increased plate counts and a much larger number of positive presumptive coliform tests.

ATCHISON, KANSAS (R.M. 423.0)

It was originally estimated that the slug would reach Atchison approximately 12 hours after St. Joseph, or about 6:00 a.m. on February 1. The chlorine demand started to increase at the Atchison water plant at midnight, Wednesday, February 2, and it was estimated that the spill had arrived at Atchison approximately midnight on February 1 since there is a one day delay between the raw water intake and the point of chlorine application. Atchison indicated approximately a seven fold increase in chlorine dosage from a normal of 5 mg/l to a maximum of 33 mg/l, which was limited by chlorinator capacity rather than chlorine demand. The full capacity of chlorine feed was continued until 7:00 p.m. February 7. There were ice jams in the Missouri River both upstream and downstream from the Atchison water intake. Atchison had a few complaints on taste. It was calculated that the time of travel from Omaha to Atchison was 158 hours. The rate of flow was calculated to be 1.3 miles per hour.

LEAVENWORTH, KANSAS (R.M. 396.8)

It had originally been estimated that the slug would reach Leavenworth 12 hours after Atchison. The effects of the fertilizer spill were first noticed on February 5. It was estimated that the slug started passing the plant about three days earlier, or about February 1 or 2. When the fertilizer spill first reached the Leavenworth water treatment plant, pumping from the River was discontinued. This plant has a storage of about 13 million gallons; and after some of this storage had been used, pumping from the River was resumed at a reduced rate. The chlorine dosage was increased from 7.3 mg/l on February 5 to a maximum of 10.2 mg/l on February 8. The discontinuance of pumping and the later reduction in pumping resulted in very few adverse effects at Leavenworth. There were no complaints of poor water quality during the period of time that the slug was passing the Leavenworth plant.

KANSAS CITY, KANSAS (R.M. 373.7)

Based on the time of flow from Sioux City to Omaha, it was estimated that the fertilizer slug would arrive at Kansas City, Kansas, about January 30.

Break-point chlorination is used at the Kansas City, Kansas, plant. On February 1, the chlorine demand increased to 2 ppm, and a two-hour testing schedule was started at 4:00 a.m. On February 1 and 2, the ammonia nitrogen concentration was .3 ppm as N and the phosphate was also .3 ppm as PO_4. The total phosphate concentration as PO_4 reached a maximum of 29 ppm at 10:00 a.m. on February 5. It was reported that there were more taste and odor complaints during the fertilizer pollution effects than at any other time during the last 35-year period.

Mr. A. W. Rumsey, Chemist, Board of Public Utilities, Kansas City, Kansas, reported to his management on February 20, 1966, as follows:

> The actual cost of the spill was 14,000 lbs. of chlorine, 5 million gallons of finished water flushed to waste with attendant labor for flushing, and 120 hours of chemist's time. We were forced to discontinue break-point chlorination for two days because it was impossible to meet the demand; and it was during this period that our finished water quality, as measured by taste and odor, deteriorated to bring a flood of complaints.

It was calculated that the time of travel from Atchison to Kansas City, Kansas, was 52 hours. The rate of flow was calculated to be 0.95 miles per hour.

KANSAS CITY, MISSOURI (R.M. 370.5)

The ammonia and phosphate concentrations in the raw water began to increase February 3, 1966. The maximum ammonia nitrogen concentration was 10.0 ppm as N at 2:00 a.m. on the 6th. No unusual treatment problems were encountered during the passage of the fertilizer spill. Break-point chlorination is not used, so no increased demand was experienced.

No taste or odor complaints were received during this period or the following four days.

LEXINGTON, MISSOURI (R.M. 318.0)

Based on the times of flow downstream from the fertilizer spill, on February 4, it was estimated that the spill would reach Lexington between 4:00 p.m. and midnight, Saturday, February 5. The time of flow from Kansas City to Lexington was estimated to be about 37 hours.

The main effect from the fertilizer spill felt at this plant was the increase in the chlorine demand. The chlorine demand before the spill was about 10 mg/l. While the polluted water was passing through the

Lexington area, the chlorine demand increased to a peak of 17 mg/l. Mr. Lee, Manager of the Missouri Water Company of Lexington, estimated that the slug of pollution reached Lexington February 5 and continued until about February 9. They maintained some free chlorine residual at all times. They had no reports of goldfish kills or taste and odor problems.

Tables 19 and 21 show information on dates and times of the passage of the fertilizer spill. The Corps of Engineers "Time of Water Travel" graph also shows this information in addition to other pertinent data. In some cases there is good correlation between cities on time of arrival of the fertilizer spill, and in other cases the correlation is poor.

One example is the Lexington data. It shows that the fertilizer spill reached Lexington before the upstream Kansas Citys. The time of arrival at Lexington was approximated by assuming that the fertilizer spill caused an increase in chlorine demand (February 5) and subtracting two days to compensate for the estimated delay in the plant. More or less short circuit flows in the plant than assumed could cause this estimate to be in error.

GLASGOW, MISSOURI (R.M. 227.0)

The chlorine feed at Glasgow was increased starting at 9:00 a.m. on February 7. Before the increase in chlorine demand, the feed was 52 pounds per million gallons. The feed was increased to a peak of 88 pounds at 8:00 a.m. on February 8. The rate was reduced to a normal feed of 56 pounds per million gallons at 11:00 a.m. on February 12.

No taste or odor or specific problems were encountered.

BOONVILLE, MISSOURI (R.M. 197.0)

On February 4, the Regional Office informed Mr. Robert Miller of the Missouri Division of Health that the effects from the fertilizer spill should reach Jefferson City by noon, February 10. Jefferson City is at River Mile 145.0 and Boonville, 197.0.

Data on Boonville treatment indicate that the rate of chlorine feed increased on the morning of February 11. The flow time through the plant has been estimated at 54 hours. This indicates that the spill began reaching the Boonville water intake early on February 9.

There were no complaints of tastes or odors during this period.

JEFFERSON CITY, MISSOURI (R.M. 145.0)

Based on Corps of Engineers and Weather Bureau estimates and the time of arrival at Omaha, it was estimated that the fertilizer slug would reach Jefferson City between February 2 and 5. The time of arrival estimate was later changed to about noon on February 10.

Analyses of raw water samples were made starting February 10. The ammonia nitrogen varied from 0.7 to 4.4 and one reading of 10.0. The level of the River began to rise shortly after the collection of samples was started. By February 11 the level had risen 1 foot and it was up about 5 to 6 feet by February 15.

The raw water nitrate concentrations as N were in a range of 0.4 to 1.2, and the total phosphate reading had a high of 6.0 mg/l as PO_4. This high reading was the first one recorded. It appears that the peak might have occurred before the first sample was taken.

The nitrate content of the finished water was shown as being 1.1 to 2.1 as N. There were no reports of excessive taste and odor complaints.

ST. LOUIS, MISSOURI (R.M. 37.0)

There was no effect on chlorine demand by the fertilizer slug. Chlorine dosage remained the same, and there was no change in residual. Normally, ammonia is fed before chlorine is added.

There was not much change in phosphate concentrations during the time the slug was passing. The phosphate readings on the raw water were as follows:

Date	Phosphates mg/l as PO_4
Feb. 3	.3
Feb. 4	.6
Feb. 7	.5
Feb. 8	.4
Feb. 9	.2
Feb. 10	.2

At the time the phosphate started coming through, the alum dosage was increased. There was high turbidity and high alum feed was required during the remainder of the month. A rise in the River and the arrival of the fertilizer occurred at about the same time. The need for increasing the alum may have been due mainly to the results of the increased streamflow.

There were no taste or odor complaints attributed to the fertilizer spill.

ST. LOUIS COUNTY, MISSOURI (R.M. 36.5)

It was reported that a marked increase in ammonia nitrogen in Missouri River water was noted at 11:30 a.m., Friday, February 11, 1966. This lasted until 5:00 a.m., Saturday, February 12, 1966 (17 hours). An increase in phosphate was also detected.

There was a slight taste to the water during this period which required carbon treatment. However, this taste could not be attributed to the increase in ammonia and phosphates.

At the time this increase in ammonia and phosphate was detected, 14.5 percent of the flow in the Missouri River came from Bagnell Dam. This dilution was thought to be of great benefit.

Chlorination facilities were adequate for removal of the ammonia; but the opinion was expressed that had it not been for the dilution from Bagnell, it is doubtful that sufficient chlorine could have been applied with existing facilities.

It was calculated that the time of travel from Kansas City, Kansas, to St. Louis County water intake was 145 hours. The rate of flow was calculated to be 2.3 miles per hour.

CAPE GIRARDEAU, MISSOURI

During the period February 16 to 19 that the fertilizer spill was in the Mississippi River passing Cape Girardeau, there was no deviation from the normal chlorine demand. The chlorine feed varied from 8 to 9 ppm. There were no reports of tastes or odors attributable to the fertilizer spill.

Arlein T. Wicks

ARLEIN T. WICKS, P.E.
Chief, Water Quality Activities

APPENDIX 1

Report by

Department of the Army
Missouri River Division
Corps of Engineers
Omaha, Nebraska

MISSOURI RIVER ICE CONDITIONS
COINCIDENT WITH FERTILIZER SPILL*

26 January through 15 February 1966

An examination was made of available records to note the ice conditions which prevailed at the time the 26 January 1966 fertilizer spill into the Missouri River near Sioux City was moving downstream. These conditions are discussed on a reach-by-reach basis for the period of time the main concentration of fertilizer was moving through each reach.

Sioux City to Omaha, 26 January through 29 January. Heavy floating ice was reported through this reach during the above period. There were no reports of any blocks.

Omaha to St. Joseph, 27 January through 6 February. Heavy floating ice was reported from all stations in this reach at the beginning of the period. However, immediately prior to 27 January, stage fluctuations at reporting stations were indicative of the formation of ice blocks which would remain in place for a short period of time (one day or less). A 24-hour stage increase of over 5 feet, together with frozen conditions, was reported at Rulo, Nebraska, on the morning of 29 January, indicating a substantial ice block formation. By the next morning (30 January), the river at Nebraska City was also reported as being frozen, with a 24-hour stage increase of 2.5 feet. Ice blocking continued to progress upstream, being quite evident at Omaha by 31 January. While the river at St. Joseph was not reported frozen through the entire period, considerable floating ice was noted. From 28 to 31 January, ice blocks above St. Joseph caused ice storage behind ice jams with a pronounced decrease in passage of water. Flow decreased from approximately 20,000 cfs on 26 January to 8,000 cfs 2 February. Normal passage of flow was not resumed until ice jams went out early in February.

St. Joseph to Kansas City, 1 February through 8 February. An ice block above Kansas City was reported at the beginning of this period and available reports indicate that, generally, the entire reach was occupied by intermittent ice cover and open water. Prior to the above dates, stages at Kansas City had fallen from 3.7 feet on 27 January to -2.0 feet on 29 January, indicating that blocking action was occurring. Ice conditions through the reach remained about as above through the entire period. By 8 February, the stage at Kansas City had risen to 3 feet above the 29 January stage, indicating an increased passage of water through the numerous upstream blocks.

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*Report by Department of the Army, Missouri River Division, Corps of Engineers, Omaha, Nebraska.

Kansas City to Boonville, 3 February through 15 February. The Missouri River at Waverly, Missouri, was reported frozen from 30 January through 8 February. Other blocks were probably in existence upstream to above Kansas City, while floating ice was reported at Boonville. On 9 and 10 February, warm temperatures combined with substantial rainfall along the Missouri River from Sioux City to the mouth caused all blocks below Sioux City to be washed out. This was accompanied by considerable floating ice and significant increases in stage. At Boonville, a 24-hour stage increase of over 10 feet was reported on 10 February. No ice blocks and only occasional floating ice were reported through the remainder of the period.

Boonville to Mouth of Missouri River, 8 February through 15 February. A few ice blocks were reported in this reach of the river, but they disintegrated at the beginning of the period. Floating ice was observed. A stage increase of 16 feet, accompanied by considerable floating ice, occurred in a 3-day interval at Hermann, Missouri, near the beginning of the period. This resulted from the rainfall and warm temperatures discussed in the preceding paragraph.

From the above discussion, a qualitative analysis of the effects of ice formation on the rate of transport of the fertilizer spill could be as follows: During the period, 26 through 28 January, while the fertilizer was being transported from Sioux City to past Omaha, the occurrence of only floating ice in this portion of the river would indicate no appreciable effect. However, while the fertilizer was moving from Omaha to below Kansas City (from 28 January through 8 February), active ice formation, resulting in channel blocks and contaminated water going into ice storage, in all probability, slowed the rate of transport considerably below what could be expected under open water conditions. The rainfall which occurred on 8 and 9 February, accompanied by the release of ice blocks, probably diluted the fertilizer concentration after these dates much more than normally could be expected. However, the lack of any ice blocking action after these dates could indicate the travel times were probably similar to open water flows of a comparable magnitude.

APPENDIX 2

Tabulated Data from

Missouri River Water Plants

Table No. 1

Omaha - Raw Water Intake
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date & Time	Turbidity Jackson Units	Hardness mg/l (as $CaCO_3$)	Alkalinity mg/l (as $CaCO_3$)	pH
January 27				
12 M - 2 PM	30	----	----	----
3 PM	30	290	188	8.2
4 PM	35	----	----	----
5 PM	70	294	190	8.1
6 PM	70	----	----	7.75
7 PM	95	----	----	----
8 PM	95	294	210	7.65
9 PM	95	----	209	7.65
10 PM	95	----	----	----
11 PM	75	----	----	7.7
January 28				
Midnight	60	279	204	7.8
1 AM	50	----	----	7.8
2 AM	50	----	----	7.85
3 AM	35	----	----	7.85
4 AM	35	284	194	8.0
5 AM	35	----	----	8.1
6 AM	30	----	----	8.1
7 AM	35	288	190	8.15

All remained fairly uniform thereafter.

Table No. 2

Omaha - Raw Water Intake
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1936

Date & Time	Ammonia Nitrogen as N (mg/l)	Ortho Phosphate as PO_4 (mg/l)	Total Phosphate as PO_4 (mg/l)
January 27			
9:00 a.m.	----	0.09	----
11:45 a.m.	0.10	----	----
12:45 p.m.	0.10	----	----
1:45 p.m.	0.20	----	----
2:30 p.m.	----	1.40	----
2:45 p.m.	0.60	----	----
3:45 p.m.	2.40	----	----
4:00 p.m.	----	7.0	----
4:45 p.m.	5.0	----	----
5:00 p.m.	----	15.7	----
5:45 p.m.	8.0	----	----
6:00 p.m.	----	28.5	55
6:45 p.m.	10.8	----	----
7:00 p.m.	----	36.0	----
7:45 p.m.	11.5	----	----
8:00 p.m.	----	43.5	----
8:30 p.m.	12.0	----	----
9:00 p.m.	12.6	39.5	57.5
10:00 p.m.	13.0	38.5	----
11:00 p.m.	9.2	20.0	----
12:00 Mid.	7.6	19.8	----
January 28			
1:00 a.m.	8.4	39.5	----
2:00 a.m.	6.0	22.0	----
3:00 a.m.	6.0	15.0	----
4:00 a.m.	6.2	12.5	----
5:00 a.m.	5.0	10.0	----
6:00 a.m.	----	7.4	----
7:00 a.m.	4.4	6.6	----
8:00 a.m.	5.2	5.0	----
9:00 a.m.	1.2	4.65	----

Table No. 2 (continued)

Omaha - Raw Water Intake
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date & Time	Ammonia Nitrogen as N (mg/l)	Ortho Phosphate as PO_4 (mg/l)	Total Phosphate as PO_4 (mg/l)
January 28 (contd)			
10:00 a.m.	1.5	4.05	----
11:00 a.m.	2.2	1.90	----
12:00 noon	1.6	1.55	----
1:30 p.m.	1.6	1.85	----
2:30 p.m.	1.3	1.70	----
3:30 p.m.	1.2	1.40	----
January 29			
8:00 a.m.	0.64	0.75	----
January 30			
7:00 a.m.	0.48	0.50	----
January 31			
8:00 a.m.	0.28	0.35	----
1:00 p.m.	0.29	----	----
February 1			
9:00 a.m.	0.18	0.19	----
1:00 p.m.	----	----	----
February 2			
9:00 a.m.	0.16	0.23	----

Table No. 3

Omaha, Nebraska
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date January	Treatment Changes							
	Alum (mg/l)		Carbon (mg/l)		Silica (mg/l)		Lime (mg/l)	Chlorine (mg/l)
	Average	Maximum	Average	Maximum	Average	Maximum		
26		2	1		0.25		121.8	1.2
27	8.5	20	4.1	17	0.35	0.50	120.2	18.
28	15.6	40	7.8	18	0.62	2.00	126.9	18.
29	8.4	10	1.0	10	0.49	0.50	119.6	1.2

Table No. 4

Council Bluffs, Iowa
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date and Time	Raw Water		1st Stage		2nd Stage		Plant Effluent	
	Ammonia Nitrogen as N (mg/l)	Phosphate as PO_4 (mg/l)	Ammonia Nitrogen as N (mg/l)	Phosphate as PO_4 (mg/l)	Ammonia Nitrogen as N (mg/l)	Phosphate as PO_4 (mg/l)	Ammonia Nitrogen as N (mg/l)	Phosphate as PO_4 (mg/l)
January 27								
10:00 p.m.	8.5	25.0						
11:00 p.m.	6.0	25.0	3.0					
January 28								
12:01 a.m.	7.5	21.5						
4:00 a.m.	6.6	15.7			0.75	<0.1		
6:00 a.m.	5.0	15.0	2.2	<0.1	1.4	<0.1		
8:00 a.m.	1.0	7.5					<0.10	<0.10
12:00 noon	6.4	3.0						
3:00 p.m.	<1.0	2.0					0.20	<0.10
6:00 p.m.							0.20	<0.10
January 29								
10:00 a.m.	1.1							

Table No. 5

St. Joseph*
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date	Chlorine Feed lbs./mg	Chlorine Feed mg/l	Chlorine Residual mg/l
Jan. 28	46	5.5	1.7
29	46	5.5	1.9
30	48	5.8	2.0
31	47	5.6	1.8
Feb. 1	57	6.8	1.6
2	46	5.5	2.4
3	37	4.4	2.4
4	46	5.5	3.0
5	41	4.9	3.0
6	44	5.3	3.0
7	70	8.4	2.3
8	81	9.7	2.2
9	68	8.2	2.1
10	65	7.8	2.1
11	63	7.6	1.8

*The fertilizer spill reached the intakes between 5:00 p.m. and 9:00 p.m. on January 31. By about 6:00 p.m. on February 5 the water quality at the intakes had improved, and free chlorine residuals could again be obtained. The delay from the intakes to the chlorine application point is approximately 18 hours.

Table No. 6

Atchison, Kansas
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date		Chlorine (mg/l) Demand	Feed	Free
February	1	3.4	5.9	
	2	3.4	5.9	2.?
	3	33. ≠	33.	0.
	4	33. ≠	33.	0.
	5	33. ≠	33.	0.
	6	24.	33.	Some present
	7	21.	30.	
	8	9.	12.	
	9	7.	9.5	
	10	5.3	7.8	
	11	(typical)		

Table No. 7

Leavenworth, Kansas *
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date	Chlorine Feed mg/l	Residual Chlorine Free mg/l	Residual Chlorine Combined mg/l
February			
5	7.3	2.0	0
6	9.2	0.8	2.+
7	9.5	0.3	1.7+
8	10.2	0.3	1.7+
9	7.9	0.1	2.+
10	8.1	0.3	2.+
11	9.8	0.6	2.+
12	7.6	2.0	2.+
13	8.3	2.0	2.+

* a. Slug reached plant about February 5.

b. Delay time from river to treatment about 3 days due to dilution and shut off.

c. On the 5th. of February, the normally free chlorine changed to combined chlorine. On the 13th. of February there was a decrease in combined chlorine and an increase in free chlorine.

d. It took 8 days to go through the plant.

e. Peak days in plant - February 6, 7, and 8.

f. Leading edge - February 5

g. Trailing edge - February 13 or 14

Table No. 8

Kansas City, Kansas - Water Plant
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966
(all concentrations in mg/l)

Date & Time	Sample	Total Phosphate (as PO_4)	Ammonia Nitrogen (as NH_3)	Nitrates (as NO_3)	Alkalinity (as $CaCO_3$)	pH	Chlorides (as Cl)	Chlorine Feed mg/l	Chlorine Break Point mg/l
Background	River	0.4	0.4	4.0-4.4	---	----	23.7	6.0	3.0
February 3									
4:00 p.m.	River	0.41	0.67	---	---	----	----	6.0	3.0
8:00 p.m.	River	0.50	0.69	5.5	---	----	27.0	----	----
12:00 Midn.	River	0.60	0.69	5.5	---	----	----	----	----
February 4									
4:00 a.m.	River	2.0	0.74	---	236	----	----	----	----
8:00 a.m.	River	2.8	1.0	5.5	237	----	28.5	6.3	3.3
10:00 a.m.	River	4.1	1.6	---	234	7.9	----	----	----
12:00 Noon	River	7.0	1.8	5.5	237	7.85	----	7.2	4.7
2:00 p.m.	River	9.2	2.4	4.4	233	7.95	----	8.6	5.1
4:00 p.m.	River	21.4	2.2	4.4	236	8.05	----	----	----
6:00 p.m.	River	10.8	3.7	4.4	---	7.85	----	----	----
8:00 p.m.	River	15.2	3.3	---	---	7.85	----	----	----
8:00 p.m.	Applied	1.3	0.02	---	---	----	----	----	----
10:00 p.m.	River	18.0	3.8	---	---	----	----	12.2	8.2
12:00 Midn.	River	16.8	4.8	6.1	---	----	----	----	----
February 5									
2:00 a.m.	River	24.0	6.4	---	---	----	----	----	----
4:00 a.m.	River	24.0	7.0	---	---	----	----	17.3	16.3
6:00 a.m.	River	26.0	7.6	---	---	----	----	23.0	21.5

Table No. 8 (continued)

Kansas City, Kansas - Water Plant
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966
(all concentrations in mg/l)

Date & Time	Sample	Total Phosphate (as PO_4)	Ammonia Nitrogen (as NH_3)	Nitrates (as NO_3)	Alkalinity (as $CaCO_3$)	pH	Chlorides (as Cl)	Chlorine Feed mg/l	Chlorine Break Point mg/l
February 5 (contd)									
8:00 a.m.	River	28.8	7.6	5.0	---	----	----	26.5	23.7
10:00 a.m.	River	29.0	7.6	---	236	7.80	----	26.7	23.7
11:00 a.m.	Applied	6.0	0.09	4.4	226	7.45	----	27.6	Off
12:00 Noon	River	29.0	7.2	4.0	---	----	28.5	28.4	Breakpoint
2:00 p.m.	River	20.0	7.6	---	---	----	----	33.0	30.0
4:00 p.m.	River	25.6	7.6	5.5	---	----	----	35.0	33.0
8:00 p.m.	River	----	7.0	---	---	----	----	35.0	----
8:00 p.m.	Applied	----	0.09	---	---	----	----	35.0	----
10:00 p.m.	River	22.0	7.0	4.4	---	----	----	36.0	34.0
									↑
February 6									Off Combined
4:00 a.m.	River	15.2	6.4	5.5	---	----	----	39.6	Residuals to
10:00 a.m.	River	12.4	5.6	5.5	---	----	----	39.6	7.5
10:00 a.m.	Applied	15.2	1.35	1.1	---	----	----	39.6	↓
12:00 Noon	River	8.4	4.4	---	---	----	----	39.6	
4:00 p.m.	River	8.4	4.4	5.5	---	----	----	39.6	Res. over 10
5:30 p.m.		----	----	---	---	----	----	33.0	----
6:40 p.m.		----	----	---	---	----	----	29.0	----
2:00 p.m.	Tap	12.8	4.0	---	---	----	----	----	----
6:00 p.m.	River	8.4	4.0	---	---	----	----	----	----
6:00 p.m.	Quick Mix	12.8	6.4	---	---	----	----	----	----
7:30 p.m.		----	----	---	---	----	----	11.0	10.0 Comb. Res.
8:00 p.m.		----	----	---	---	----	----	8.0	7.6 " "
9:00 p.m.		----	----	---	---	----	----	6.0	5.7 " "
10:20 p.m.		----	----	---	---	----	----	4.5	4.0 " "
11:00 p.m.		----	----	---	---	----	----	4.0	3.5 " "
10:00 p.m.	River	10.0	3.7	5.5	---	----	----	----	----

Table No. 8 (continued)

Kansas City, Kansas - Water Plant
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966
(all concentrations in mg/l)

Date & Time	Sample	Total Phosphate (as PO_4)	Ammonia Nitrogen (as NH_3)	Nitrates (as NO_3)	Alkalinity (as $CaCO_3$)	pH	Chlorides (as Cl)	Chlorine Feed mg/l	Chlorine Break Point mg/l	
February 7										
4:00 a.m.	River	9.4	3.4	3.8	---	----	----	----	----	
10:00 a.m.	River	7.6	2.8	---	---	----	----	----	----	
10:00 a.m.	Quick Mix	11.6	4.8	5.5	---	----	----	4.0	3.5	Comb. Res.
4:00 p.m.	River	7.0	2.1	---	---	----	----	----	----	
10:00 p.m.	River	4.6	2.0	5.5	---	----	----	----	----	
February 8										
4:00 a.m.	River	5.2	1.6	5.5	---	----	----	----	----	
9:00 a.m.	River	5.0	1.5	5.5	---	----	----	----	----	
9:00 a.m.	Quick Mix	3.2	1.7	5.5	---	----	----	----	----	
12:00 noon		----	----	---	---	----	----	20.	15.0	
12:30 p.m.		----	----	---	---	----	----	18.0	15.0	
1:00 p.m.		----	----	---	---	----	----	16.0	13.4	
2:30 p.m.		----	----	5.5	---	----	----	14.4	11.0	
8:00 p.m.	River	2.8	1.6	---	---	----	----	12.4	7.0	
9:00 p.m.		----	----	---	---	----	----	11.5	8.0	
February 9										
9:00 a.m.		----	----	---	---	----	----	11.5	7.5	
4:00 a.m.	River	1.9	.76	---	---	----	----	----	----	
1:00 p.m.	River	.56	.75	---	---	----	----	----	----	
1:00 p.m.	Quick Mix	1.3	1.1	---	---	----	----	----	----	
7:00 p.m.	River	.50	.52	---	---	----	----	10.6	6.0	
9:00 p.m.		----	----	---	---	----	----	9.5	5.5	

Table No. 8 (continued)

Kansas City, Kansas - Water Plant
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966
(all concentrations in mg/l)

Date & Time	Sample	Total Phosphate (as PO_4)	Ammonia Nitrogen (as NH_3)	Nitrates (as NO_3)	Alkalinity (as $CaCO_3$)	pH	Chlorides (as Cl)	Chlorine Feed mg/l	Chlorine Break Point mg/l
February 10									
1:00 a.m.	River	.50	.65	---	---	----	----	8.4	5.0
10:30 a.m.	Quick Mix	.50	.65	---	---	----	----	----	----
5:00 p.m.		---	---	---	---	----	----	7.5	3.8

Table No. 9

Kansas City, Missouri - Raw Water
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966
(all concentrations as mg/l)

Date & Time	Ortho - Phosphate (as PO_4)	Ammonia (as NH_3)	Nitrogen (as N)
February 3			
4:00 p.m.	.24	.17	.13
6:00 p.m.	.26	.24	.19
8:00 p.m.	.28	.24	.19
10:00 p.m.	.33	.24	.19
12:00 midnight	.42	.25	.20
February 4			
2:00 a.m.	.38	.24	.19
4:00 a.m.	.40	.28	.22
6:00 a.m.	.56	.24	.19
8:00 a.m.	.50	.61	.50
10:00 a.m.	.46	.73	.59
12:00 noon	.52	.73	.59
2:00 p.m.	1.16	.61	.50
4:00 p.m.	2.48	.73	.79
6:00 p.m.	3.28	.97	.79
8:00 p.m.	4.00	1.09	.89
10:00 p.m.	5.4	1.2	.98
12:00 midnight	8.2	5.5	4.5
February 5			
2:00 a.m.	8.0	9.7	8.0
4:00 a.m.	11.8	9.7	8.0
6:00 a.m.	9.4	9.7	8.0
8:00 a.m.	13.8	8.5	7.0
10:00 a.m.	13.8	8.5	7.0
12:00 noon	13.4	10.8	8.9

Table No. 9 (continued)

Kansas City, Missouri - Raw Water
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966
(all concentrations as mg/l)

Date & Time	Ortho - Phosphate (as PO_4)	Ammonia (as NH_3)	Nitrogen (as N)
February 5 (continued)			
2:00 p.m.	14.0	10.2	8.36
4:00 p.m.	16.4	10.9	10.9
6:00 p.m.	16.2	10.9	8.9
8:00 p.m.	11.2	10.9	8.9
10:00 p.m.	16.0	10.4	8.5
12:00 midnight	14.0	12.2	10.0
February 6			
2:00 a.m.	13.2	12.2	10.0
4:00 a.m.	11.0	12.2	10.0
6:00 a.m.	10.8	9.7	8.0
8:00 a.m.	10.0	10.9	8.9
10:00 a.m.	8.4	10.9	8.9
12:00 noon	8.0	9.7	8.0
2:00 p.m.	13.2	12.2	10.0
4:00 p.m.	11.0	12.2	10.0
6:00 p.m.	10.8	9.7	8.0
8:00 p.m.	10.0	10.9	8.9
10:00 p.m.	8.4	10.9	8.9
12:00 midnight	8.0	9.7	8.0
February 7			
2:00 a.m.	9.0	9.0	7.4
4:00 a.m.	7.2	8.4	6.9
6:00 a.m.	6.4	4.9	4.0
8:00 a.m.	4.6	5.3	4.3
10:00 a.m.	4.0	4.9	4.0
12:00 noon	3.8	4.4	3.6
2:00 p.m.	3.7	3.7	3.0
4:00 p.m.	3.3	4.2	3.4
6:00 p.m.	3.1	3.6	3.0
8:00 p.m.	2.8	.61	.50
10:00 p.m.	2.9	1.5	1.2
12:00 midnight	2.5	1.5	1.2

Table No. 9 (continued)

Kansas City, Missouri - Raw Water
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966
(all concentrations as mg/l)

Date & Time	Ortho - Phosphate (as PO_4)	Ammonia (as NH_3)	Nitrogen (as N)
February 8			
2:00 a.m.	2.3	.97	.79
4:00 a.m.	2.2	.99	.81
6:00 a.m.	1.9	1.8	1.5
8:00 a.m.	1.8	2.1	1.7
10:00 a.m.	2.0	2.0	1.6
12:00 noon	1.6	2.5	2.1
2:00 p.m.	1.4	4.8	3.9
4:00 p.m.	1.4	4.4	3.6
6:00 p.m.	.42	4.4	3.6

Table No. 10

Kansas City, Missouri - Treated Water
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Friday - 2/4/66

Raw NH_3 (free)	0.63 ppm by direct Nesslerization	
Raw NH_3 (total)	0.65 ppm by distillation	
Del.NH_3 (total)	0.85 ppm by distillation	
Delivered PO_4	ORTHO	TOTAL
* 4-6 miles	.01	.17
10-12 miles	.00	.27
18-20 miles	.02	.40
Clearwell	.02	.24
7:00 p.m. 2/3/66	.03	.30
3:00 a.m. 2/4/66	.03	.12
11:00 a.m. 2/4/66	.07	.57

Saturday
Sunday — No NH_3's or PO_4's were conducted on delivered water.

Monday - 2/7/66

Raw NH_3 (total)	1.8 ppm by distillation	
Del.NH_3 (total)	2.7 ppm by distillation	
Delivered PO_4	ORTHO	TOTAL
* 4- 6 miles	.09	.49
10-12	.08	.63
18-20	.05	.45
16-18	.05	.37
10-12	.09	.41
6- 8	.09	.72
16-18	.07	.45
Clearwell	.10	.77
7:00 p.m. 2/6/66	.15	.70
3:00 a.m. 2/7/66	.15	.63
11:00 a.m. 2/7/66	.43	.74

Tuesday - 2/8/66

Delivered NH_3 (free)	* 4-6	2.7 ppm
" " "	8-10	3.4 ppm
" " "	10-12	3.6 ppm
" " "	16-18	2.9 ppm

Table No. 10 (continued)

Kansas City, Missouri - Treated Water
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Tuesday - 2/8/66 (continued)

Phosphates (delivered)	ORTHO ONLY	
	* 4- 6	.17 ppm
	8-10	.09 ppm
	10-12	.10 ppm
	16-18	.08 ppm

Wednesday - 2/9/66

Delivered NH_3 (free)	* 4-6	1.0 ppm
	10-12	2.5 ppm
	16-18	3.0 ppm
	6-8	2.0 ppm

Phosphates (delivered)	ORTHO ONLY	
	* 4-6	.12 ppm
	10-12	.14 ppm
	16-18	.19 ppm
	6-8	.21 ppm

*Miles from water treatment plant.

Table No. 11

Lexington, Missouri
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date	No.4 Basin Free Chlorine (mg/1)	Free Chlorine Top Filter (mg/1)	Chloramines Tap (mg/1)	Chlorine lbs/MG	Feed mg/1
February					
2	1.7	2.+	2.+	81	9.7
3*	1.4	1.8	1.8	96	11.5
4	0.8	1.7	1.9	95	11.4
5	0.5	1.7	1.7	113	13.6
6	0.5	2.+	2.+	137	16.5
7	0.5	1.9	2.+	112	13.5
8	0.2	0.5	2.+	143	17.1
9	0.5	0.5	2.+	135	16.2
10	0.5	0.5	2.+	134	16.1
11	0.4	0.6	2.+	127	15.2
12	0.3	0.7	2.+	116	13.9
13	0.5	1.4	2.+	110	13.2
14	1.3	2.0	2.+	138	16.6
15	2.0	2.0	2.+	111	13.3
16	1.5	2.0	2.+	118	14.2
17	0.7	2.+	2.+	130	15.6
18	0.6	2.+	2.+	139	16.7
19	0.5	2.0	2.+	110	13.2
20	0.5	2.0	2.+	155	18.6
21	1.7	2.+	2.+	140	16.8
22	2.0	2.+	2.+	149	17.9
23	2.0	2.+	2.+	130	15.6
24	1.6	2.+	2.+	118	14.2
25	1.4	2.+	2.+	114	12.5
26	1.1	2.+	2.+	107	12.9
27	1.3	2.+	2.+	111	13.3
28	1.8	2.+	2.+	108	13.0

*Fertilizer spill entered basins

Table No. 12

Glasgow

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966
(all concentrations as mg/l)

Date & Time	Chlorinator Setting lbs./24 hours	Free Cl_2 15 minutes mg/l	Cl_2 Residual 4 hours mg/l	lbs. Cl_2 per million gallons	Cl_2 mg/l
February 7					
8:00 a.m.	26	0.8	1.5	52	6.2
9:00 a.m.	28	2.0	1.5	56	6.7
10:00 a.m.	36	3.0	1.5	72	8.6
11:00 a.m.	36	3.0	1.5	72	8.6
Shut Down					
3:00 p.m.	40	2.5	1.0	80	9.6
4:00 p.m.	40	2.5	1.2	80	9.6
5:00 p.m.	40	2.5	1.5	80	9.6
Shut Down					
February 8					
8:00 a.m.	44	0.8	2.0	88	10.3
9:00 a.m.	42	3.0	2.0	84	10.1
10:00 a.m.	42	2.5	2.0	84	10.1
11:00 a.m.	42	2.5	2.0	84	10.1
From 9:00 a.m. February 8 to morning of February 12 there was very little change in chlorine demand and free residual.					
February 12					
8:00 a.m.	42	3.5	2.5	84	10.1
9:00 a.m.	36	3.0	2.5	72	8.6
10:00 a.m.	30	2.5	2.0	60	7.2
11:00 a.m.	28	2.5	2.0	56	6.7
12:00 noon	28	2.5	2.0	56	6.7

Table No. 13

Boonville, Missouri
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date	Total Gallons	Chlorine Feed lbs.	Chlorine Feed mg/l	Chlorine Residual mg/l
February 10	1,162,000	156	16.1	10.0
11	1,047,000	204	23.5	11.0
12	895,000	150	20.1	7.0
13	626,000	55	25.0	10.0
14	1,102,000	248	27.0	7.0
15	1,271,000	308	23.3	10.0
16	1,195,000	342	31.0	10.0
17	1,298,000	264	24.5	5.0
18	1,313,000	348	32.0	10.0
19	1,051,000	168	18.4	4.0
20	580,000	104	21.5	3.5
21	1,316,000	160	14.7	3.8
22	1,262,000	136	12.8	3.8

Table No. 14

Jefferson City, Missouri - Raw Water
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

(all values except pH in mg/l)

Date & Time	pH	Ammonia Nitrogen (as NH_3)	Ammonia Nitrogen (as N)	Nitrites (as N)	Nitrates (as N)	Ortho Phosphate (as PO_4)	Total Dissolved Phosphate* (as PO_4)	Total Phosphate** (as PO_4)
February 10								
11:00 a.m.	8.8	2.7	2.2	0.01	0.6	4.0	4.5	6.0
3:00 p.m.		2.2	1.8	0.015	1.2	3.0	4.5	5.5
7:00 p.m.		1.1	0.9	0.015	0.6	3.0	3.0	5.5
11:00 p.m.		0.8	0.	0.015	0.8	2.5	3.0	4.5
February 11								
3:00 a.m.	7.1	1.9	1.6	0.015	0.8	1.2	1.4	2.6
7:00 a.m.		1.5	1.2	0.015	0.7	0.7	0.8	1.8
11:00 a.m.		1.2	1.0	0.005		0.8	0.8	1.6
3:00 p.m.		2.9	2.4	0.005		0.6	0.8	1.8
7:00 p.m.		2.9	2.4			0.6		
11:00 p.m.		2.9	2.4			0.5		
February 12								
3:00 a.m.	7.6	1.3	1.1		0.4	0.6		
7:00 a.m.		1.2	1.0			0.6		
11:00 a.m.		1.2	1.0	0.01	0.8	0.6	0.8	1.6
3:00 p.m.		2.9	2.4			0.5		
7:00 p.m.		1.9	1.6			0.4		
11:00 p.m.		2.4	2.0			0.4		

*Samples filtered.
**Samples not filtered.

Table No. 14 (continued)

Jefferson City, Missouri - Raw Water
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

(all values except Ph in mg/l)

Date & Time	pH	Ammonia Nitrogen (as NH_3)	Nitrogen (as N)	Nitrites (as N)	Nitrates (as N)	Ortho Phosphate (as PO_4)	Total Dissolved Phosphate* (as PO_4)	Total Phosphate** (as PO_4)
Feoruary 13								
3:00 a.m.		2.2	1.8			0.4	0.4	
7:00 a.m.		2.2	1.8			0.4		
11:00 a.m.		2.4	2.0			0.4		
3:00 p.m.		2.7	2.2			0.4		
7:00 p.m.		2.9	2.4			0.4	0.6	
11:00 p.m.		2.7	2.2		0.5	0.4		
February 14								
3:00 a.m.		2.4	2.0			0.4		
7:00 a.m.		2.4	2.0			0.6		
3:00 p.m.		5.3	4.4				0.7	
7:00 p.m.		3.9	3.2				0.6	
11:00 p.m.		2.9	2.4		1.0			
February 15								
3:00 a.m.		2.4	2.0				0.8	
7:00 a.m.		4.8	4.0				0.6	
11:00 a.m.	7.6	12.1	10.0				0.6	
3:00 p.m.		2.4	2.0					
7:00 p.m.		2.9	2.4					
11:00 p.m.		2.2	1.8					
February 16								
3:00 a.m.	7.5	2.2	1.8				0.6	
7:00 a.m.		2.2	1.8					
11:00 a.m.		2.2	1.8					

*Samples filtered.
**Samples not filtered.

Table No. 15

Jefferson City, Missouri
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date	Detention Time from Low Service Pump to Point of Chlorine Application (Hours)	Detention Time from Chlorine Application Point to Filter Effluent (Hours)	Chlorine Feed		Chlorine Residual (mg/l)
			lbs./mg	mg/l	
February 10	21	15	121	14.4	3.0
11	21	15	124	14.9	3.0
12	24	17	128	15.3	3.0
13	21	15	115	13.8	3.0
14	21	15	118	14.2	3.0
15	21	15	116	13.9	3.0
16	21	15	115	13.8	3.0
17	21	15	105	12.6	3.0
18	19	14	107	12.8	3.0
19	19	14	111	13.3	3.0
20	21	15	112	13.4	3.0

Table No. 16

Jefferson City, Missouri*
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Finished Water Samples

Date	Time	Phosphate as PO_4 (mg/l)	Nitrates as NO_3 (mg/l)
**February 11	3:00 p.m.	0.7	
11	7:00 p.m.	0.7	9.2
11	11:00 p.m.	0.6	
12	3:00 a.m.	0.7	
12	7:00 a.m.	0.8	9.0
12	11:00 a.m.	0.8	
12	3:00 p.m.	0.5	7.5
12	7:00 p.m.	0.7	
12	11:00 p.m.	0.4	
13	3:00 a.m.	0.6	
13	7:00 a.m.	0.6	8.5
13	11:00 a.m.	0.4	
13	3:00 p.m.	0.4	9.5
14	11:00 a.m.	0.5	
14	3:00 p.m.	0.4	2.6
14	7:00 p.m.	0.5	
14	11:00 p.m.	0.5	
16	8:00 a.m.	0.5	4.9
16	11:00 a.m.	0.5	
16	3:00 p.m.	0.5	
16	7:00 p.m.	0.5	
17	3:00 a.m.	0.1	
17	8:00 a.m.	0.4	4.9
17	11:00 a.m.	0.1	
17	7:00 p.m.	0.1	
17	11:00 p.m.	0.1	4.9
18	3:00 a.m.	0.1	
18	7:00 a.m.	0.1	
18	11:00 a.m.	0.1	4.9
18	3:00 p.m.	0.1	

*Flow time through treatment process approximately 31 hours.

**Samples 2/11/66 through 2/16/66 were collected after application of about .5 ppm phosphate. Starting February 17 the phosphate samples were collected before the phosphate application.

Table No. 17

St. Louis County
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Missouri River Water

Date and Time	Flow cfs	Ammonia Nitrogen as NH_3 (mg/l)	Phosphates as PO_4 (mg/l) Ortho	Poly Phos. Dissolved	Poly Phos. Total
February 9					
8:00 a.m.	20	0.25	0.21	0	0.23
4:00 p.m.					
8:00 p.m.		0.4			
February 10					
8:00 a.m.	115	0.65	0.1	0	2.2
11:00 a.m.					
1:30 p.m.					
4:00 p.m.		0.60			
8:00 p.m.		0.65			
11:00 p.m.					
February 11					
4:00 a.m.		0.55			
5:00 a.m.		0.55			
6:00 a.m.		0.65			
7:00 a.m.		0.70			
8:00 a.m.	140	0.65	0.43	0.05	1.72
11:30 a.m.		0.85			
3:00 p.m.		1.05			
8:00 p.m.		1.05	1.1	0.3	2.1
11:00 p.m.					
February 12					
1:00 a.m.		1.0			
4:00 a.m.		1.0			
5:00 a.m.		0.75			
6:00 a.m.		0.65			
7:00 a.m.		0.60			
8:00 a.m.	138	0.65			
11:00 a.m.		0.55			
1:00 p.m.		0.60			
2:30 p.m.		0.55			
4:00 p.m.					
8:00 p.m.		0.4			
11:00 p.m.					

Table No. 17 (continued)

St. Louis County
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Missouri River Water

Date and Time	Flow cfs	Ammonia Nitrogen as NH_3 (mg/l)	Phosphates as PO_4 (mg/l)		
			Ortho	Poly Phos. Dissolved	Poly Phos. Total
February 13					
8:00 a.m.	139	0.25			
11:00 a.m.					
4:00 p.m.					
8:00 p.m.		0.3			
11:00 p.m.					
February 14					
8:00 a.m.	140	0.35			
4:00 p.m.					
8:00 p.m.		0.40			
11:00 p.m.					

Table No. 18

Cape Girardeau, Missouri
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date and Time	Chlorine Feed lbs./day	Chlorine Feed mg/l	Chlorine Residual - mg/l Filters	Chlorine Residual - mg/l Clearwell
February 16				
12:00 noon	180	8	2.-	2.
2:00 p.m.	"	"	2.-	2.
4:00 p.m.	"	"	2.-	2.-
6:00 p.m.	"	"	1.4+	2.-
8:00 p.m.	"	"	1.4+	1.4+
10:00 p.m.	"	"	1.4+	1.4+
12:00 midnight	"	"	1.4+	1.4+
February 17				
1:00 a.m.	"	"	1.4+	1.4+
2:00 a.m.	"	"	1.4+	2.-
3:00 a.m.	"	"	1.4+	2.
4:00 a.m.	"	"	1.4+	2.
5:00 a.m.	"	"	1.4+	2.
6:00 a.m.	"	"	2.-	2.
7:00 a.m.	"	"	2.	2.
8:00 a.m.	"	"	2.	2.
9:00 a.m.	"	"	2.	2.
10:00 a.m.	"	"	2.	2.
11:00 a.m.	"	"	2.	2.
12:00 noon	"	"	2.-	2.
1:00 p.m.	"	"	1.4+	2.-
2:00 p.m.	"	"	1.4	1.4+
3:00 p.m.	"	"	1.4	1.4+
4:00 p.m.	"	"	1.4	1.4+
5:00 p.m.	"	"	1.4-	1.4+
6:00 p.m.	"	"	1.4-	1.4+
7:00 p.m.	"	"	1.4-	1.4+
8:00 p.m.	"	"	1.4-	1.4
9:00 p.m.	"	"	1.4-	1.4
10:00 p.m.	"	"	1.4-	1.4
11:00 p.m.	"	"	1.4	1.4
12:00 midnight	"	"	1.4	1.4

Table No. 18 (continued)

Cape Girardeau, Missouri
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Date and Time	Chlorine Feed lbs./day	Chlorine Feed mg/l	Chlorine Residual - mg/l Filters	Chlorine Residual - mg/l Clearwell
February 18				
1:00 a.m.	180	8	1.4	1.4
2:00 a.m.	"	"	1.4+	1.4+
3:00 a.m.	"	"	1.4+	1.4+
4:00 a.m.	"	"	1.4+	1.4+
5:00 a.m.	"	"	1.4+	1.4+
6:00 a.m.	"	"	1.4+	1.4+
7:00 a.m.	"	"	1.4	1.4+
8:00 a.m.	"	"	1.4	1.4+
9:00 a.m.	190	8.5	1.4	1.4
10:00 a.m.	"	"	1.4	1.4
11:00 a.m.	"	"	1.4	1.4
12:00 noon	"	"	1.4-	1.4
1:00 p.m.	"	"	1.4-	1.4
2:00 p.m.	"	"	1.4-	1.4
3:00 p.m.	"	"	1.+	1.4-
4:00 p.m.	"	"	1.+	1.4-
5:00 p.m.	"	"	1.	1.4-
6:00 p.m.	"	"	1.+	1.4-
7:00 p.m.	"	"	1.+	1.4-
8:00 p.m.	"	"	1.+	1.4-
9:00 p.m.	"	"	1.4-	1.4
10:00 p.m.	"	"	1.4-	1.4
11:00 p.m.	"	"	1.4-	1.4
12:00 midnight	"	"	1.4-	1.4
February 19				
1:00 a.m.	"	"	1.4-	1.4
2:00 a.m.	"	"	1.4-	1.4
3:00 a.m.	"	"	1.4-	1.4
4:00 a.m.	"	"	1.4-	1.4
5:00 a.m.	"	"	1.4-	1.4
6:00 a.m.	"	"	1.4-	1.4
7:00 a.m.	"	"	1.4-	1.4
8:00 a.m.	"	"	1.4-	1.4
9:00 a.m.	200	9.0	1.4	1.4
10:00 a.m.	"	"	1.4	1.4
11:00 a.m.	"	"	1.4	1.4
12:00 noon	"	"	1.4-	1.4
1:00 p.m.	"	"	1.4-	1.4
2:00 p.m.	"	"	1.4-	1.4
3:00 p.m.	"	"	1+	1.4-
4:00 p.m.	"	"	1+	1.4-

Table No. 19

Time of Arrival

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1960

Location	Missouri River Mile	Fertilizer Spill Arrival at Water Intake (Estimates)*					
		Leading Edge		Peak		Trailing Edge	
		Date	Time	Date	Time	Date	Time
1. Sioux City, Ia.	730.5	Jan. 26	5:15 a.m.	Jan. 26	5:30 a.m.		
2. Omaha, Neb.	626.2	Jan. 27	1:45 p.m.	Jan. 27	10:00 p.m.	Jan. 31	8:00 p.m.
3. Council Bluffs, Ia.	618.9	(Assume same as Omaha.)					
4. St. Joseph, Mo.	452.2	Jan. 31	6:00 p.m.	Feb. 8	Noon	Feb. 10	
5. Atchison, Ks.	423	Feb. 1	12:00 p.m.	Feb. 3	Noon	Feb. 10	
6. Leavenworth, Ks.	396.8	Feb. 2		Feb. 5		Feb. 9	
7. Kansas City, Ks.	373.7	Feb. 3	4:00 p.m.	Feb. 5	4:00 p.m.	Feb. 9	Noon
8. Kansas City, Mo.	370.5	Feb. 3	4:00 p.m.	Feb. 6	2:00 a.m.	Feb. 9	
9. Lexington, Mo.	318	Feb. 3		Feb. 6		Feb. 11	
10. Glasgow, Mo.	227	Feb. 7		-------		Feb. 12	
11. Boonville, Mo.	197	Feb. 9	a.m.	Feb. 16		Feb. 19	
12. Jefferson City, Mo.	145	Feb. 11		Feb. 14		Feb. 17	
13. St. Louis, Mo.	37.0	(No appreciable changes noted.)					
14. St. Louis County, Mo.	36.5	Feb. 9	10:00 a.m.	Feb. 11	5:00 p.m.	Feb. 13	8:00 a.m.
15. Cape Girardeau, Mo.	**	(No appreciable changes noted.)					

*Adjusted for delay in plant.

**Mississippi River mile 1020 (about 125 miles downstream from St. Louis.).

Table No. 20

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Location	Normal Chlorine Feed (mg/l)	Chlorination Free or Combined	Water Intake to Chlorination - Delay
Omaha, Neb.	1.2	Free	3 hours
Council Bluffs, Ia.	1.0	Combined	11 hours
St. Joseph, Mo.	4.2 to 4.8	Free	18 hours
Atchison, Ks.	5.	Free	24 hrs.
Leavenworth, Ks.	7.	Free	3 days
Kansas City, Ks.	6.	Free	18 hours
Kansas City, Mo.	1.2	Combined	(No change in chlorine feed.)
Lexington, Mo.	10.	Free	2 days
Glasgow, Mo.	6.2	Free	
Boonville, Mo.	13.	Free	54 hours
Jefferson City, Mo.	12.	Free	4 hours
St. Louis, Mo.	2.6	Combined	(No change in chlorine feed.)
St. Louis County, Mo.		Free	
Cape Girardeau, Mo.	8 to 9	Free	

Table No. 21

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Location	River Mile	Peak		Time of Travel From Previous Location (Hours)	Distance From Previous Location (Miles)	Rate of Travel From Previous Location (Miles Per Hour)
		Date	Time			
1. Sioux City, Ia.	730.5	Jan. 26	5:30 a.m.			
2. Omaha, Neb.	626.2	Jan. 27	9:00 p.m.	40.5	104.3	2.6
3. Council Bluffs, Ia.	618.9			(Assume same as Omaha)		
4. St. Joseph, Mo.	452.2					
5. Atchison, Ks.	423.0	Feb. 3	Noon	158.0	203.2	1.3
6. Leavenworth, Ks.	396.8	Feb. 5				
7. Kansas City, Ks.	373.7	Feb. 5	4:00 p.m.	52.0	49.3	0.95
8. Kansas City, Mo.	370.5			(Same as Kansas City, Ks.)		
9. Lexington, Mo.	318.0					
10. Glasgow, Mo.	227.0					
11. Boonville, Mo.	197.0	Feb. 16				
12. Jefferson City, Mo.	145.0	Feb. 14				
13. St. Louis, Mo.	37.0					
14. St. Louis County, Mo.	36.5	Feb. 11	5:00 p.m.	145.0	337.2	2.3

APPENDIX 3

Graphs

Graphic Data Based on Data in Appendix 2

Exhibit No. 1

Omaha

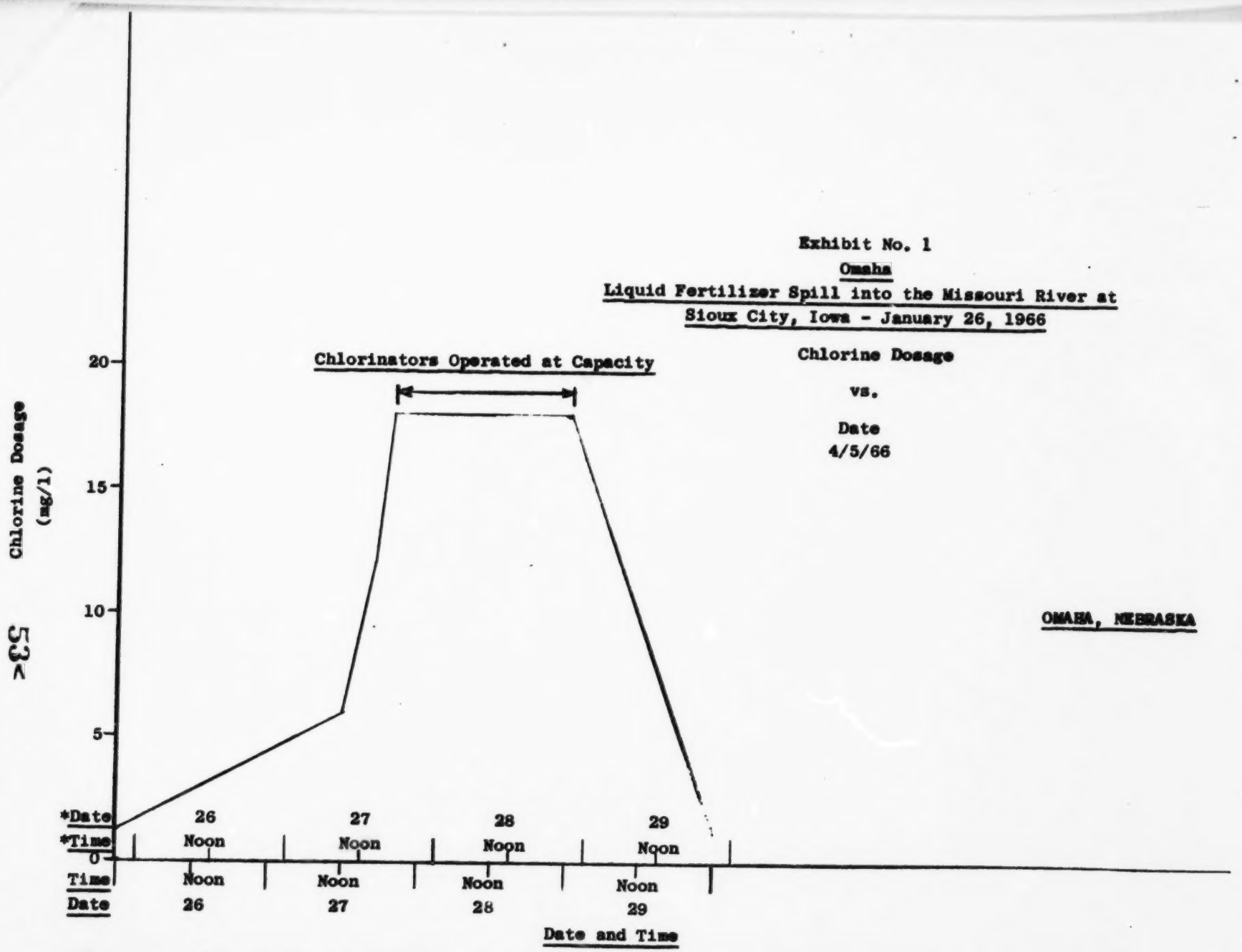
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Chlorine Dosage

vs.

Date

4/5/66



OMAHA, NEBRASKA

53<

*Adjusted to indicate the 3-hour delay in the plant. Data plotted using dates below line. Dates above line indicate estimated corresponding time at intake.

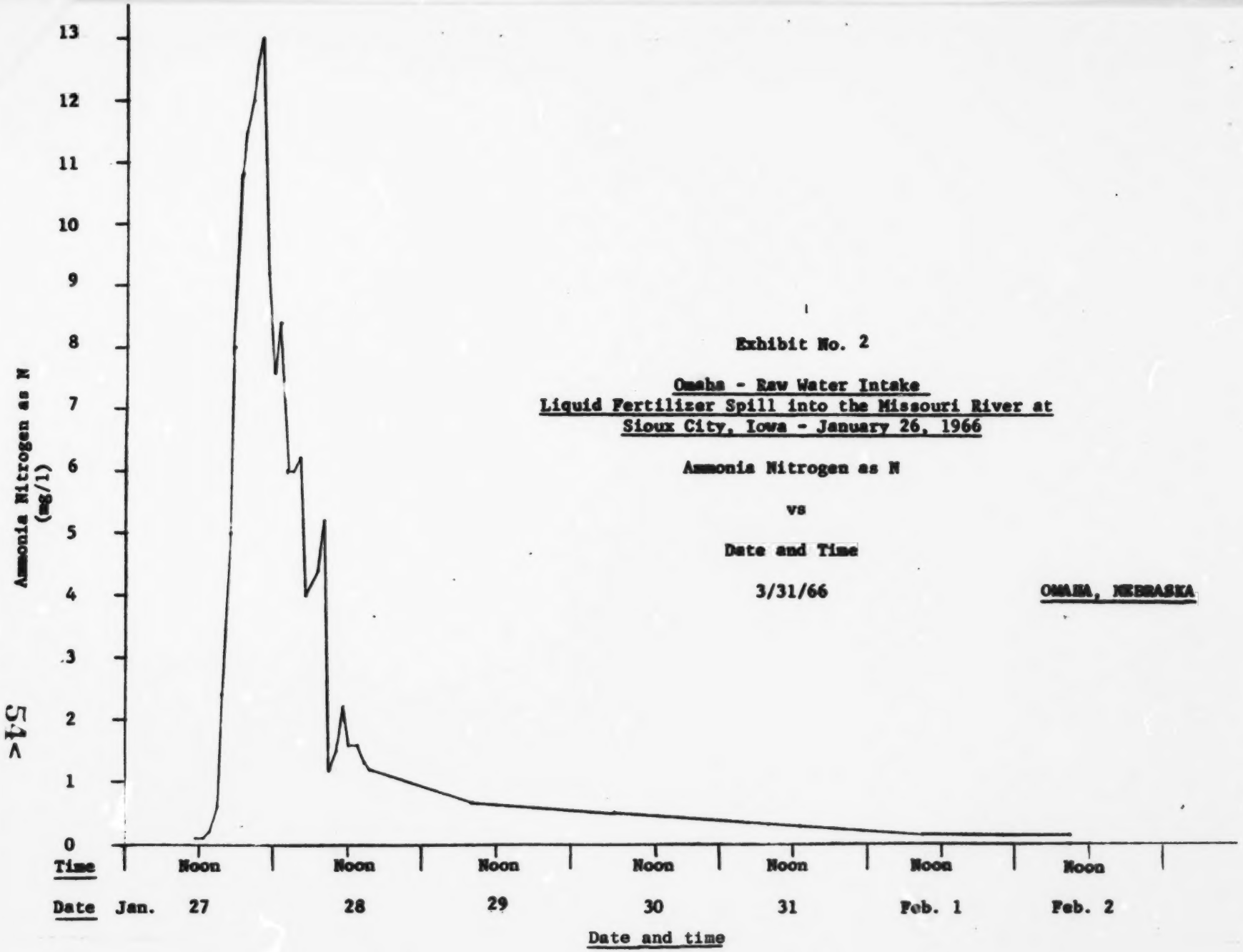


Exhibit No. 2
Omaha - Raw Water Intake
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966
Ammonia Nitrogen as N
vs
Date and Time
3/31/66
OMAHA, NEBRASKA
Ammonia Nitrogen as N (mg/l)
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Time
Noon
Date
Jan. 27
28
29
30
31
Feb. 1
Feb. 2
Date and time

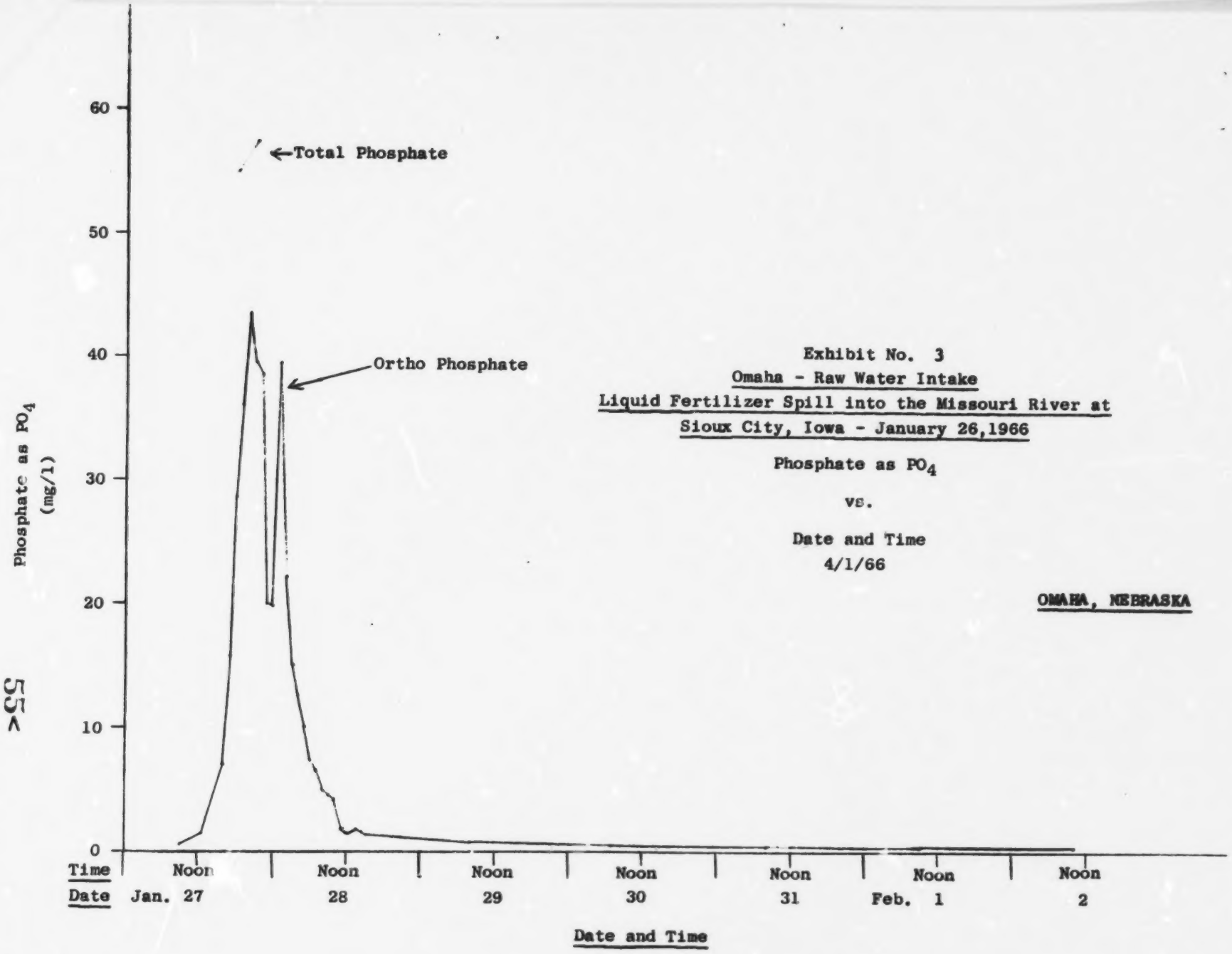


Exhibit No. 3

Omaha - Raw Water Intake

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26,1966

Phosphate as PO_4

vs.

Date and Time

4/1/66

OMAHA, NEBRASKA

55

Exhibit No. 4

Council Bluffs - Raw Water

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

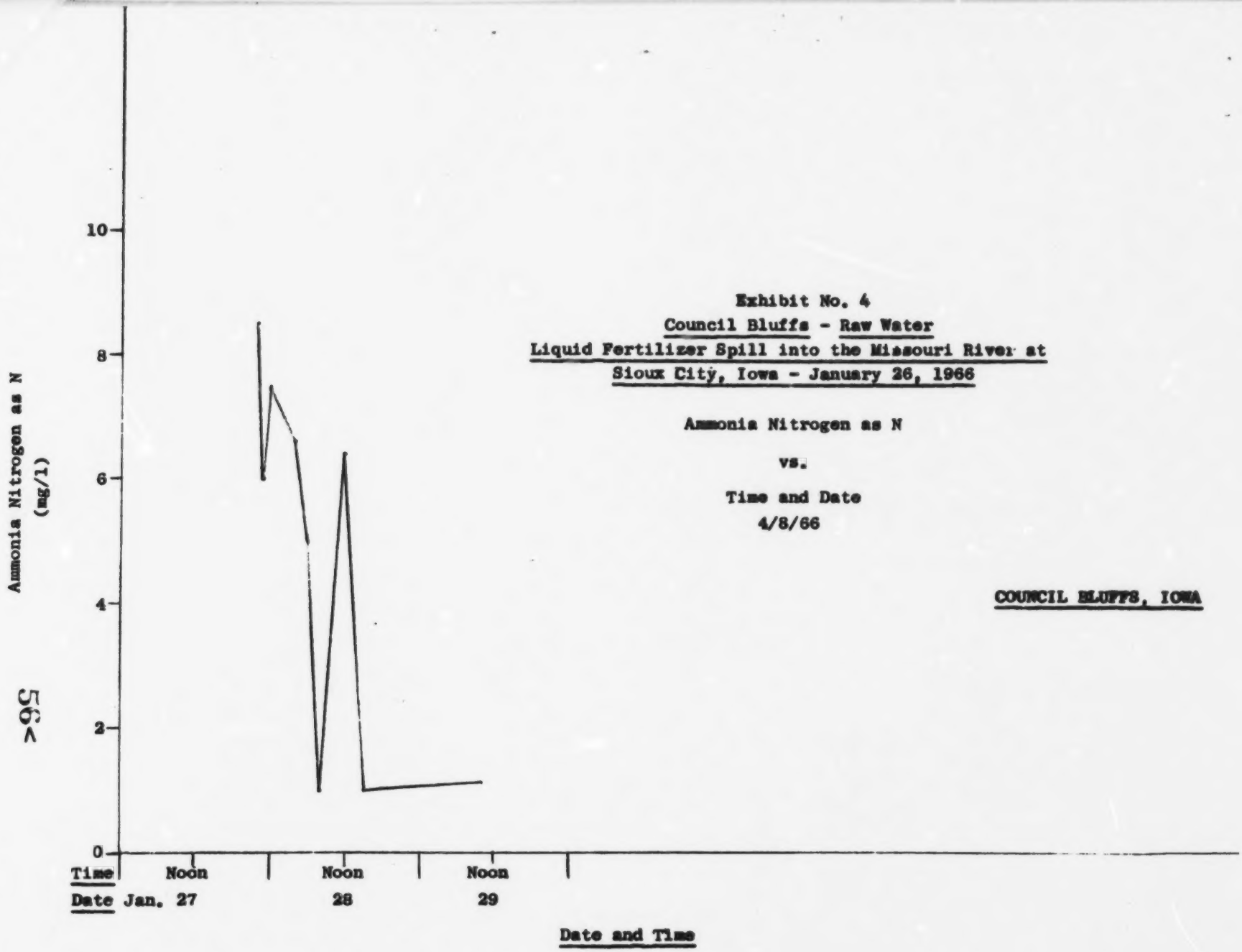
Ammonia Nitrogen as N

vs.

Time and Date

4/8/66

COUNCIL BLUFFS, IOWA



56

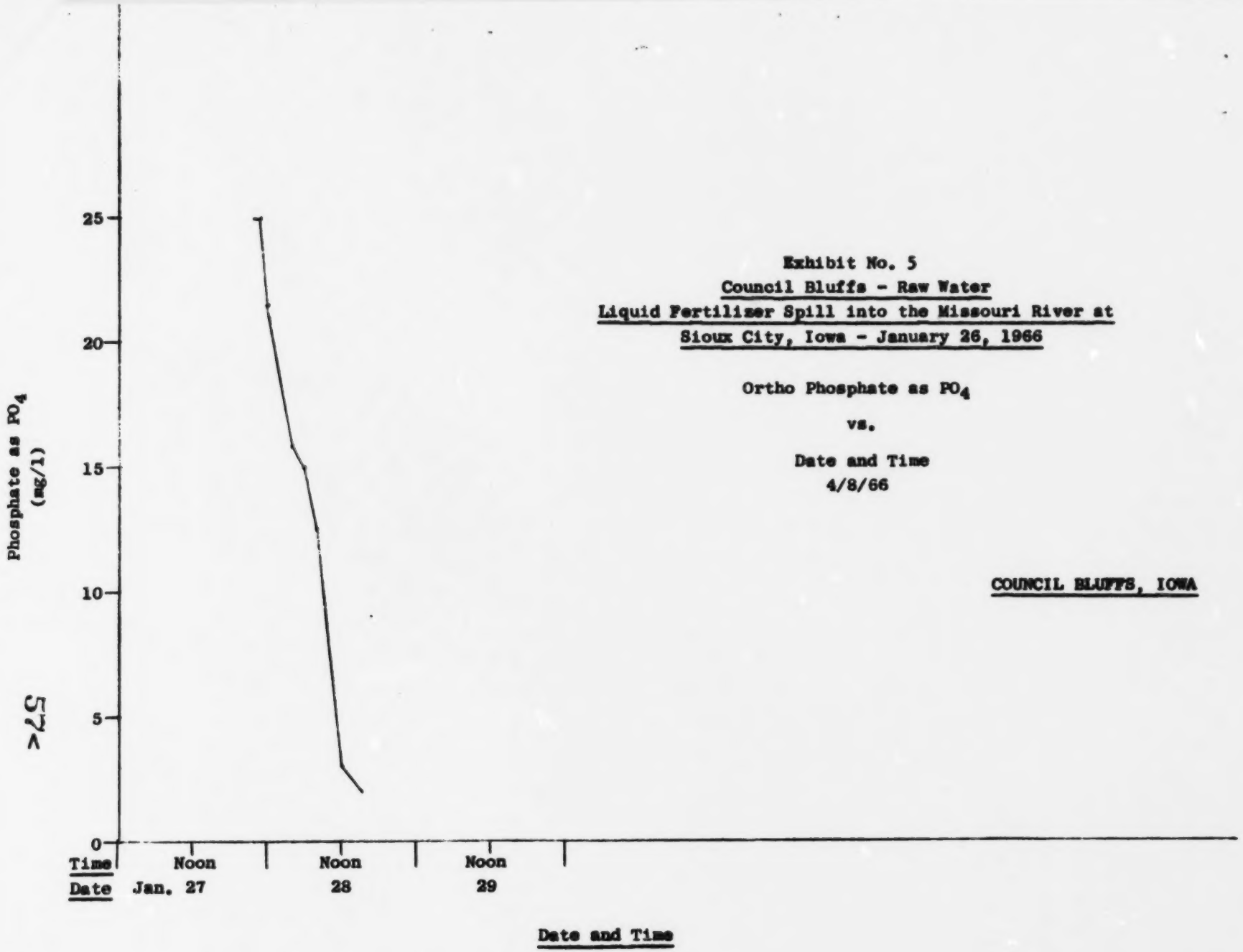
Exhibit No. 5
Council Bluffs - Raw Water
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Ortho Phosphate as PO_4

vs.

Date and Time
4/8/66

COUNCIL BLUFFS, IOWA



57<

Exhibit No. 6

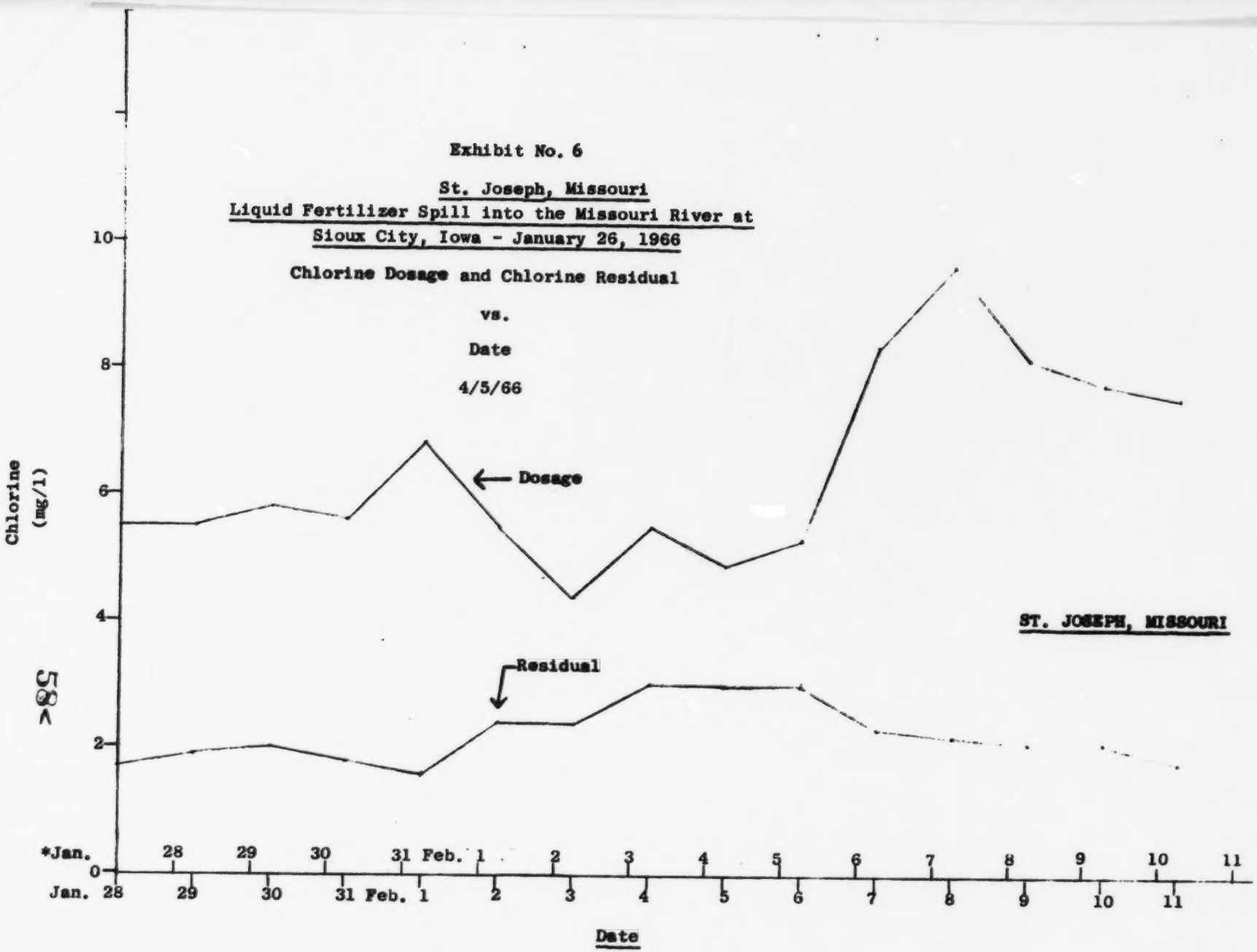
St. Joseph, Missouri
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Chlorine Dosage and Chlorine Residual

vs.

Date

4/5/66



58<

*Adjusted to indicate the 18-hour delay in the plant. Data plotted using dates below line. Dates above line indicate estimated corresponding time at water intake.

Exhibit No. 7

Atchison, Kansas

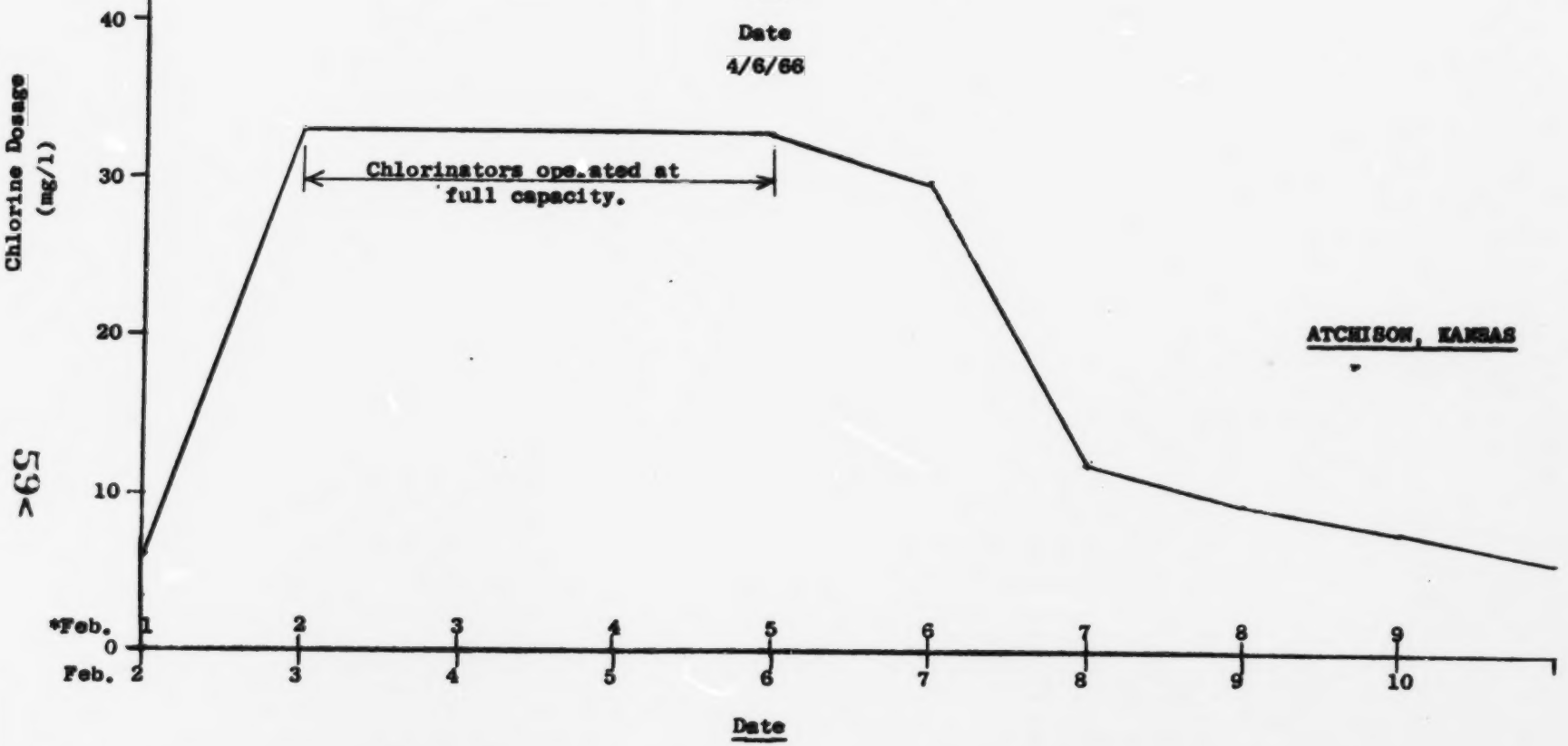
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Chlorine Dosage

vs.

Date

4/6/66



*Adjusted to indicate the 24-hour delay in the plant. Data plotted using dates below line. Dates above line indicate estimated corresponding time at water intake.

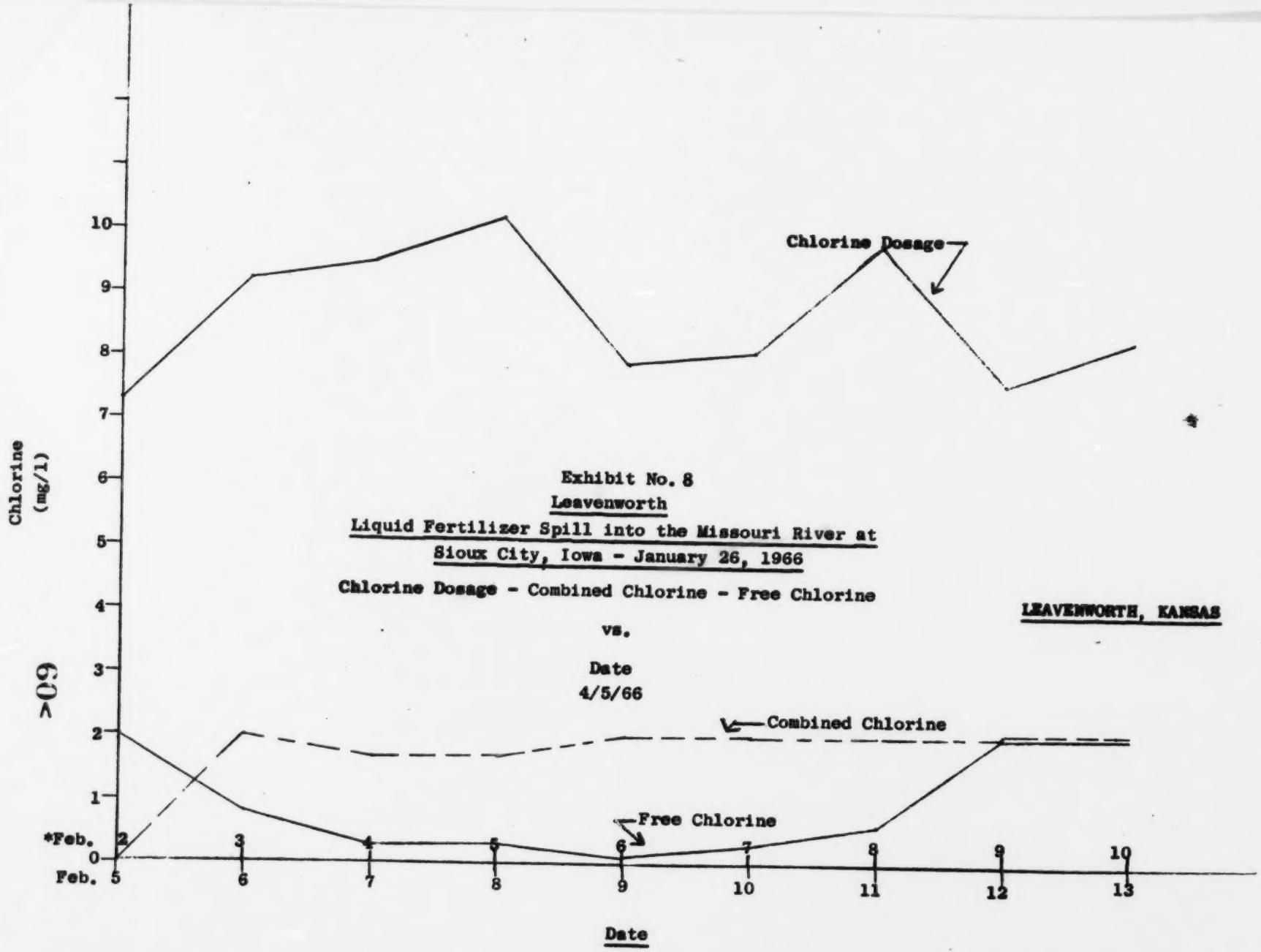


Exhibit No. 8

Leavenworth

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Chlorine Dosage - Combined Chlorine - Free Chlorine

vs.

Date

4/5/66

LEAVENWORTH, KANSAS

>69

*Adjusted to indicate the 3-day delay in the plant. Data plotted using dates below line. Dates above line indicate estimated corresponding time at water intake.

Exhibit No. 9

Kansas City, Kansas

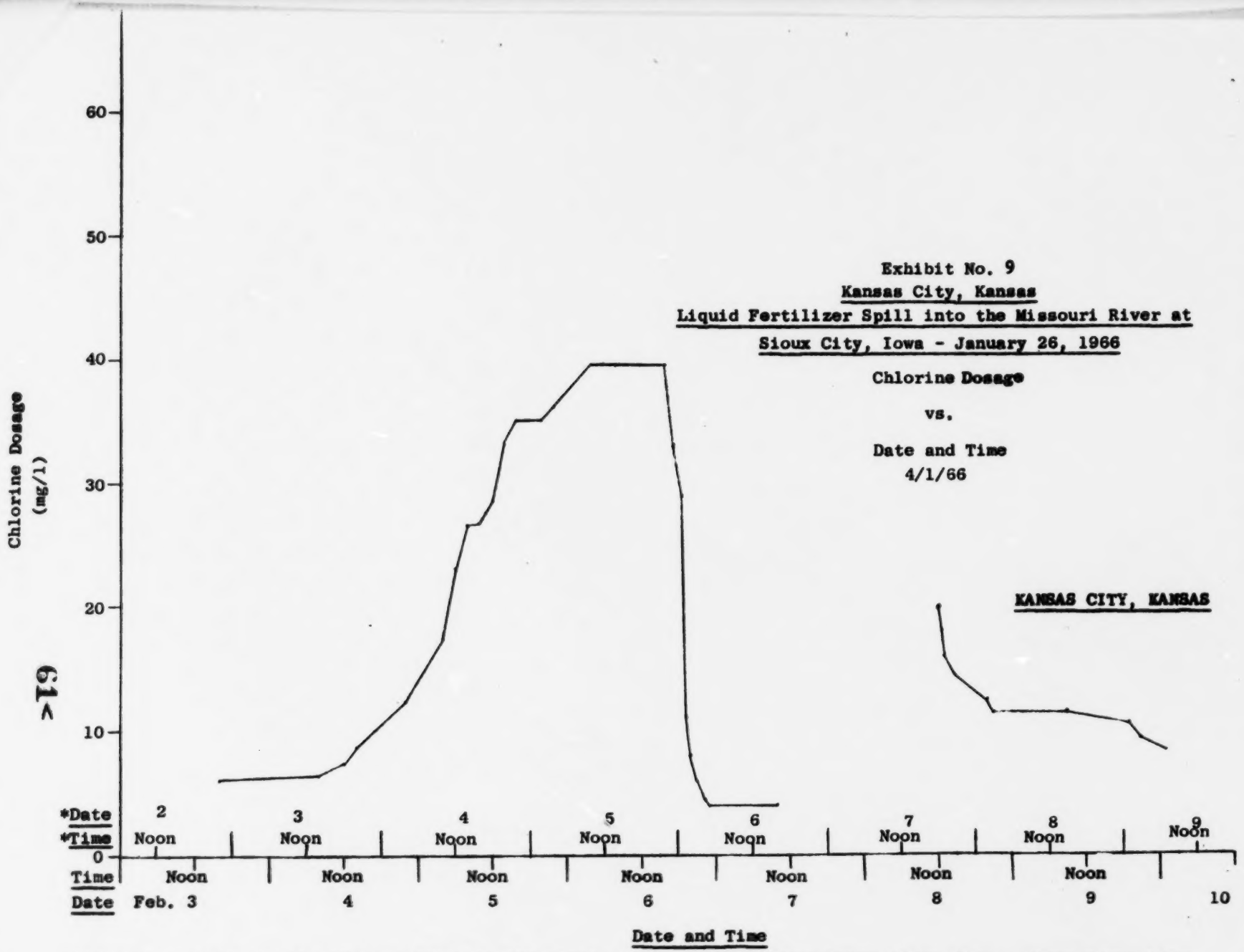
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Chlorine Dosage

vs.

Date and Time

4/1/66



*Adjusted to indicate the 18-hour delay in the plant. Data plotted using dates below line. Dates above line indicate estimated corresponding time at water intake.

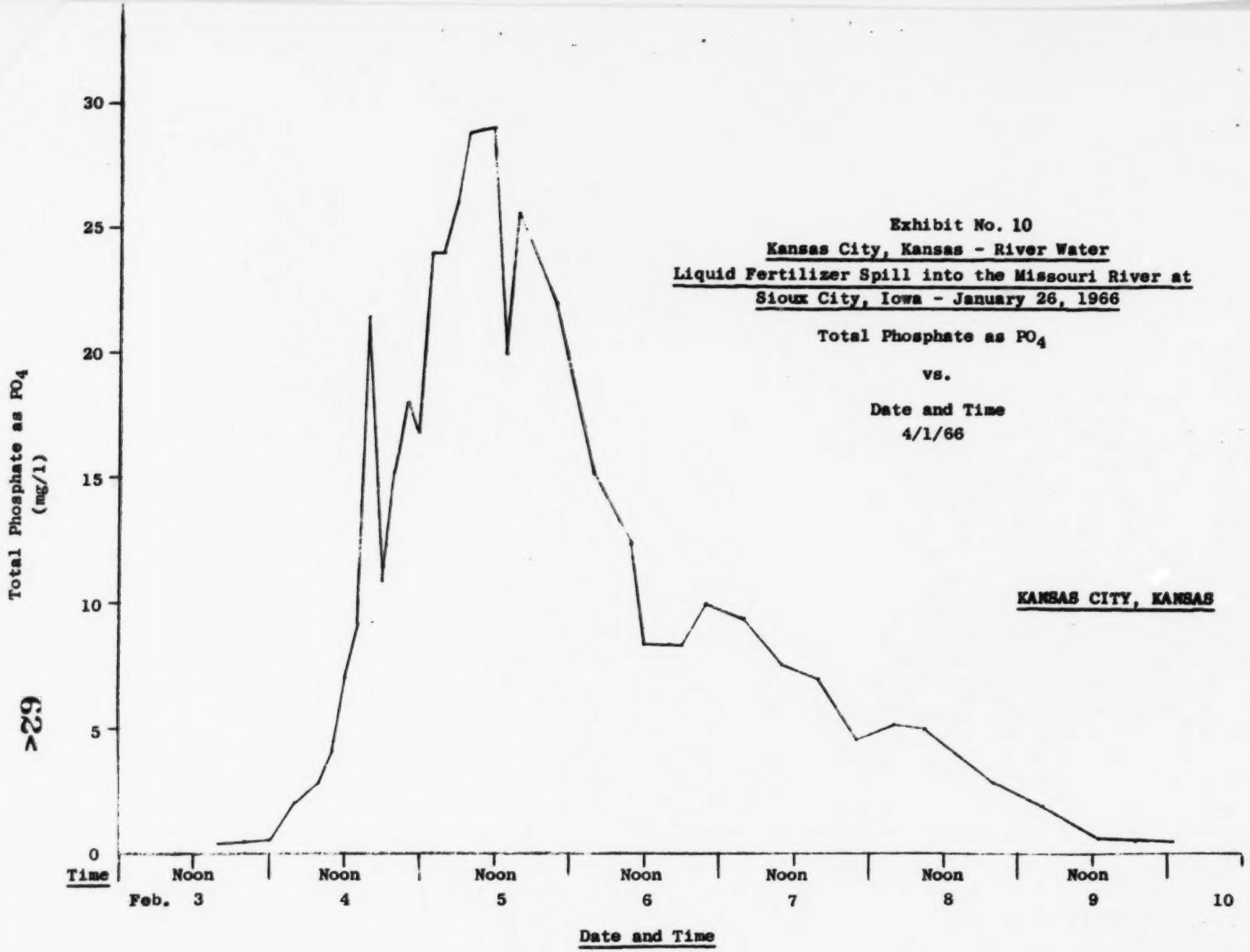


Exhibit No. 10
Kansas City, Kansas - River Water
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966
Total Phosphate as PO_4
vs.
Date and Time
4/1/66
KANSAS CITY, KANSAS
Total Phosphate as PO_4 (mg/l)
>29
30
25
20
15
10
5
0
Time
Noon
Feb. 3
4
5
6
7
8
9
10
Date and Time

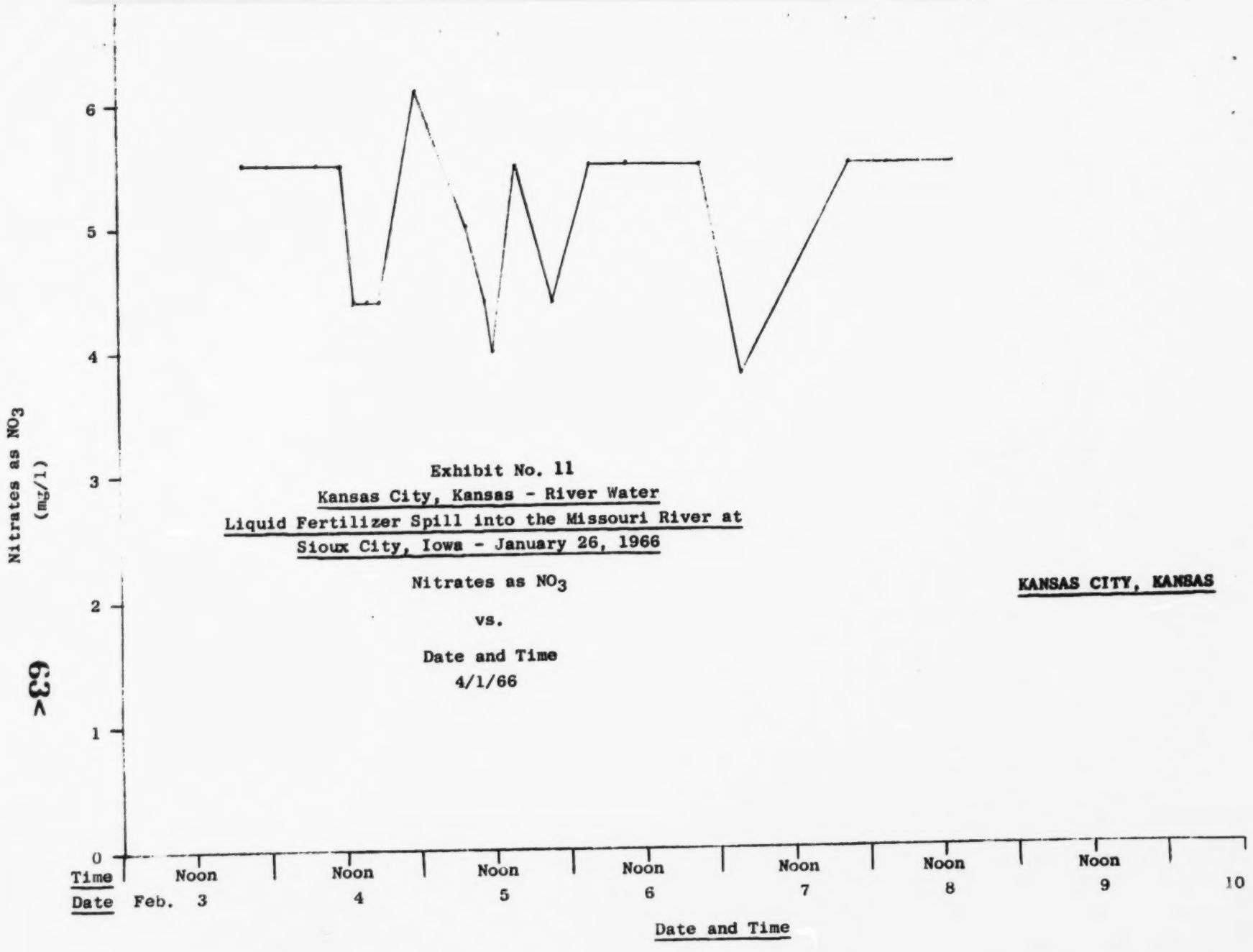


Exhibit No. 11

Kansas City, Kansas - River Water

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Nitrates as NO_3

vs.

Date and Time

4/1/66

KANSAS CITY, KANSAS

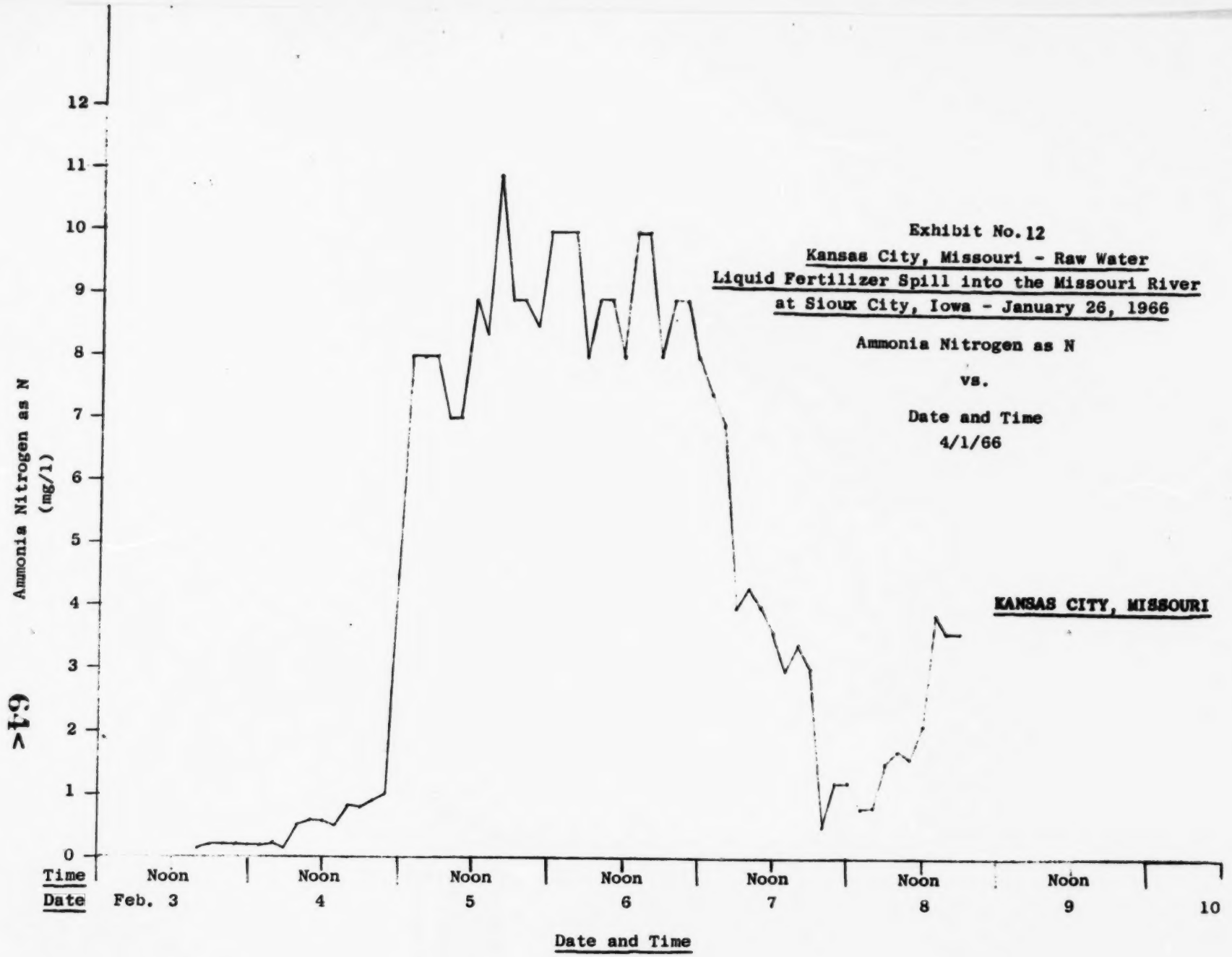


Exhibit No. 12
Kansas City, Missouri - Raw Water
Liquid Fertilizer Spill into the Missouri River
at Sioux City, Iowa - January 26, 1966
Ammonia Nitrogen as N
vs.
Date and Time
4/1/66
KANSAS CITY, MISSOURI
Ammonia Nitrogen as N (mg/l)
>1.4
0
1
2
3
4
5
6
7
8
9
10
11
12
Time
Date
Noon
Feb. 3
4
5
6
7
8
9
10
Date and Time

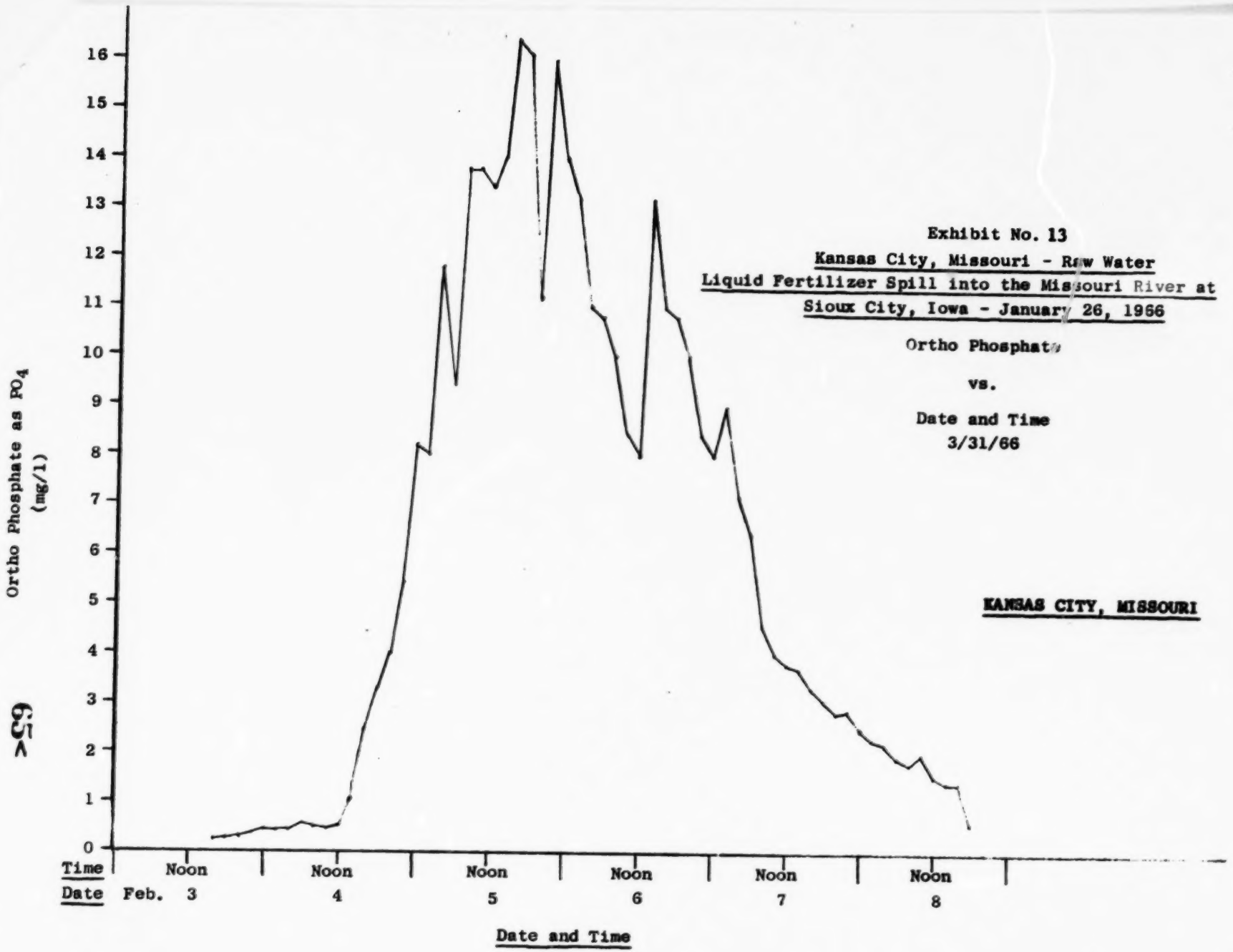
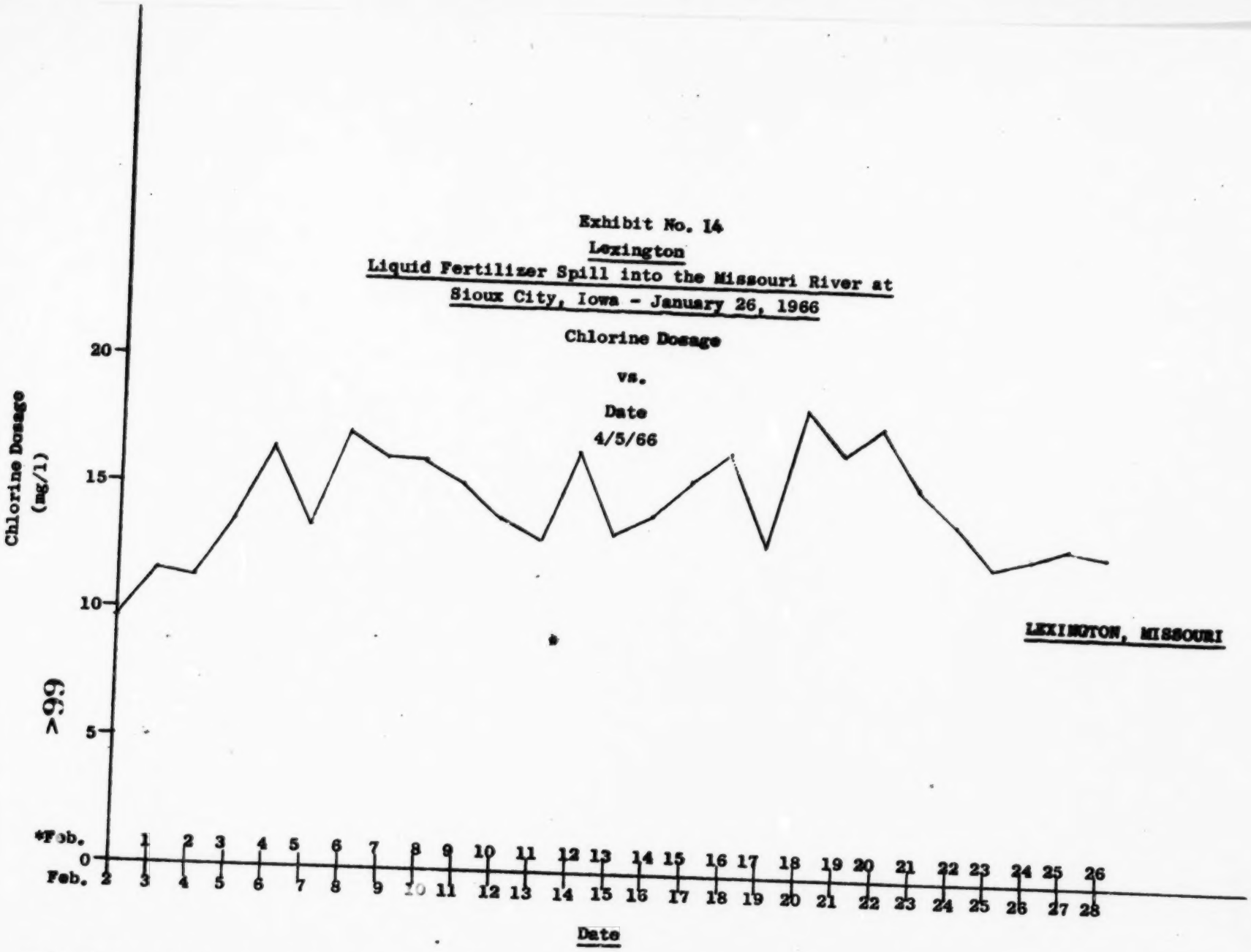


Exhibit No. 13
Kansas City, Missouri - Raw Water
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966
Ortho Phosphate
vs.
Date and Time
3/31/66
KANSAS CITY, MISSOURI
Ortho Phosphate as PO4 (mg/l)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Time
Date
Feb. 3
Noon
4
5
6
7
8
Date and Time

Exhibit No. 14

Lexington

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966



*Adjusted to indicate the 2-day delay in the plant. Data plotted using dates below line. Dates above line indicate estimated corresponding time at water intake.

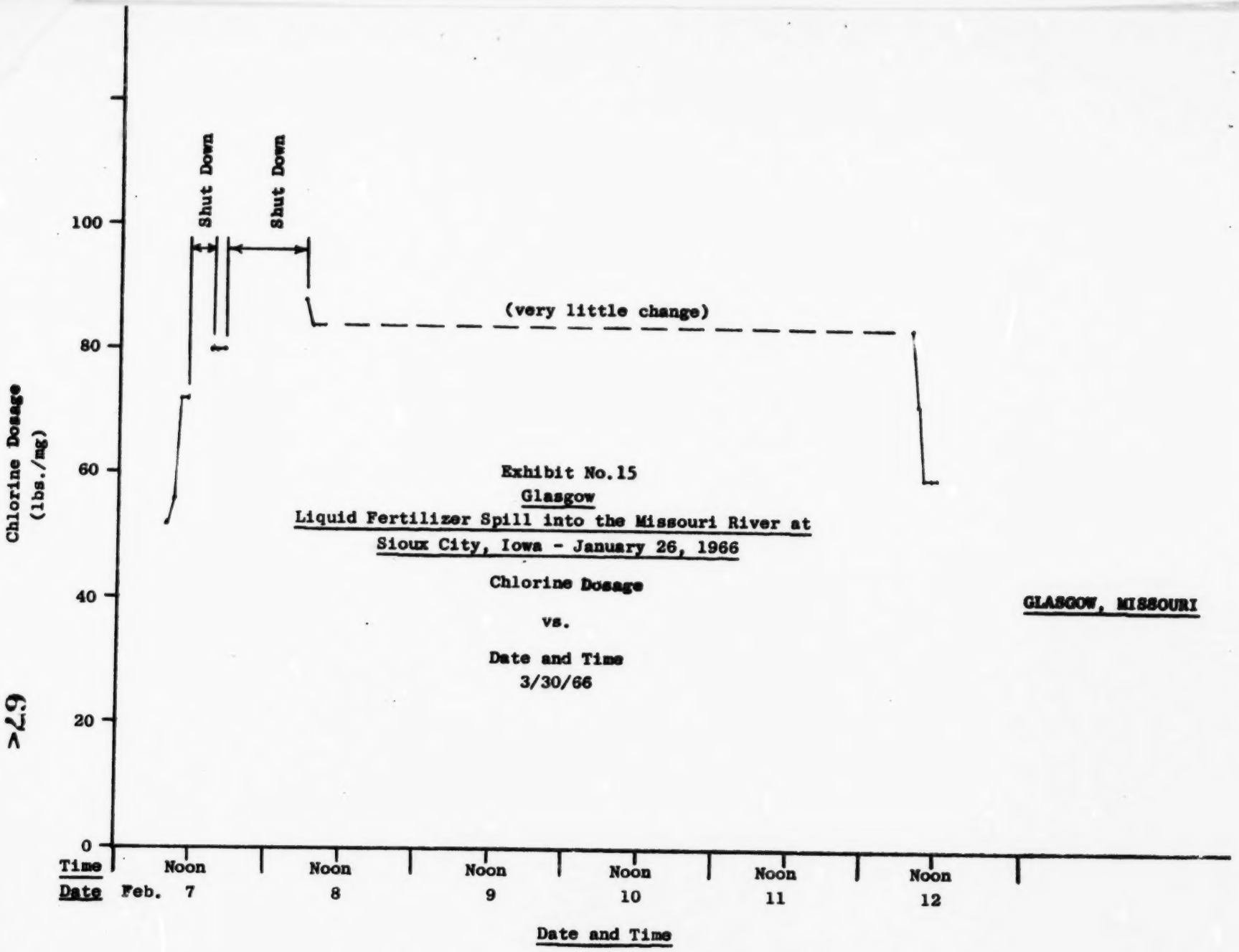


Exhibit No. 15
Glasgow
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Chlorine Dosage

vs.

Date and Time
3/30/66

GLASGOW, MISSOURI

>2.9

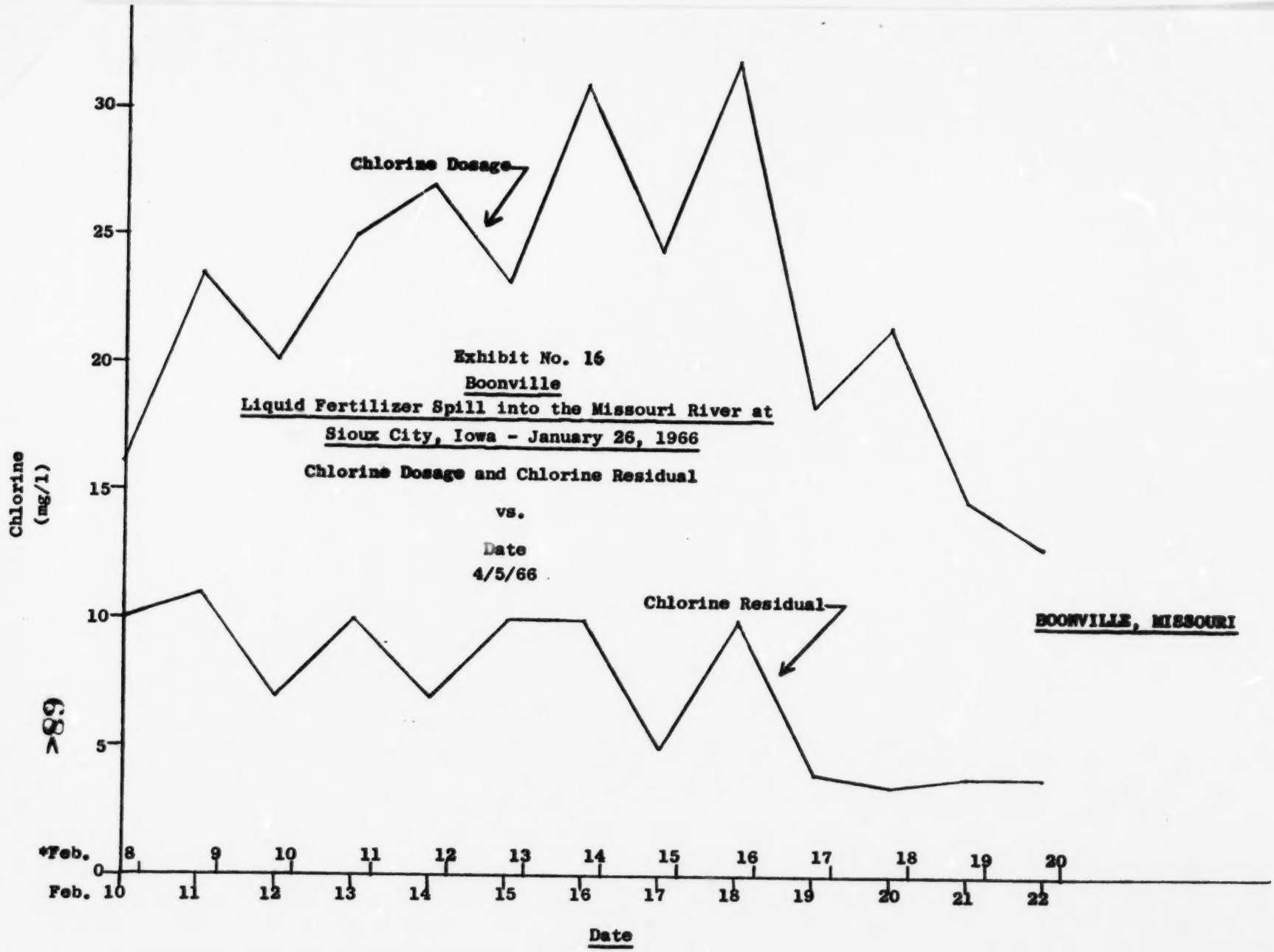


Exhibit No. 16

Boonville

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Chlorine Dosage and Chlorine Residual

vs.

Date

4/5/66

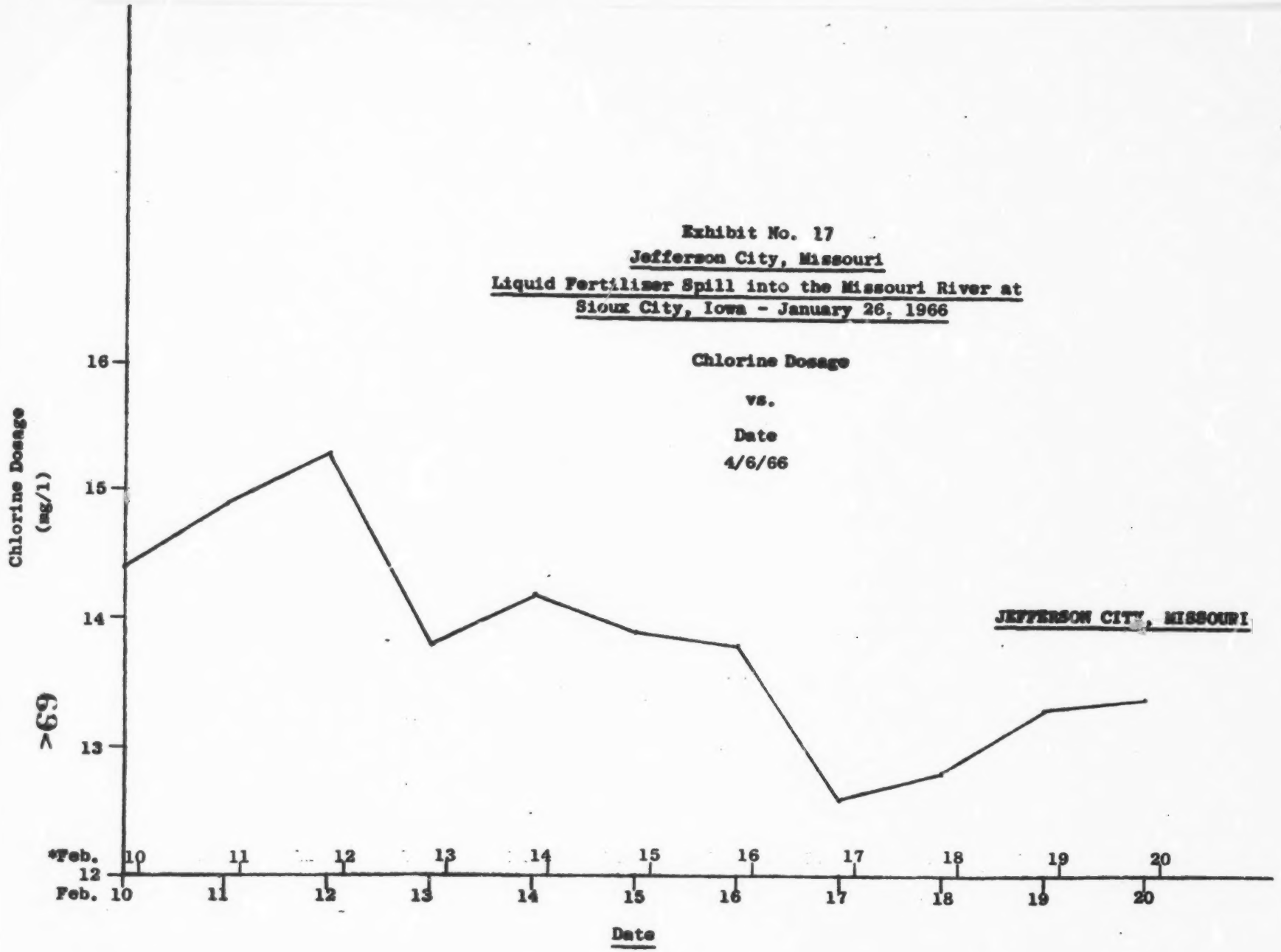
BOONVILLE, MISSOURI

*Adjusted to indicate the 54-hour delay in the plant. Data plotted using dates below line. Dates above line indicate estimated corresponding time at water intake.

Exhibit No. 17

Jefferson City, Missouri

Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966



*Adjusted to indicate the 4-hour delay in the plant. Data plotted using dates below line. Dates above line indicate estimated corresponding time at water intake.

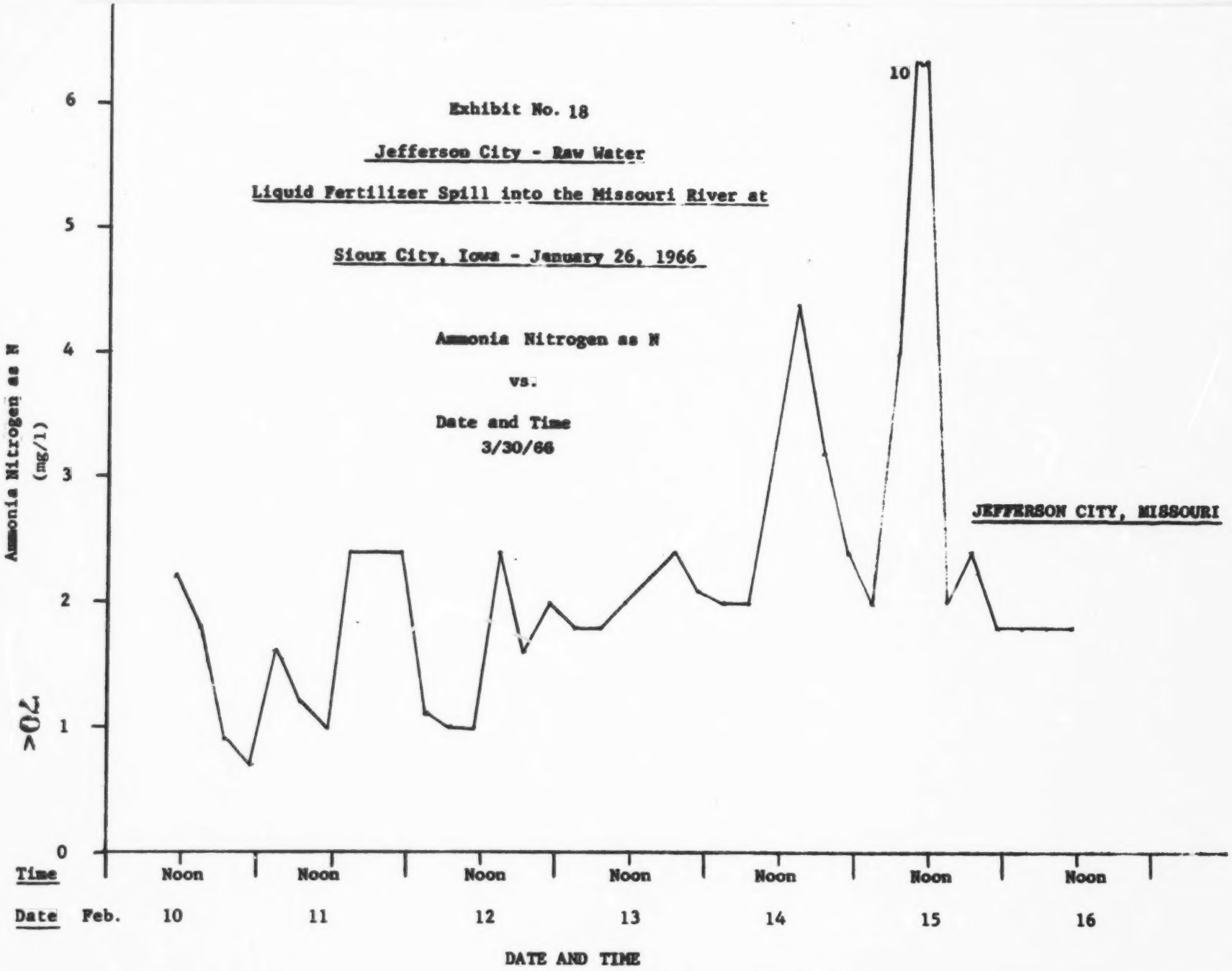


Exhibit No. 18
Jefferson City - Raw Water
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966
Ammonia Nitrogen as N
vs.
Date and Time
3/30/66
JEFFERSON CITY, MISSOURI
Ammonia Nitrogen as N (mg/l)
>02
0
1
2
3
4
5
6
10
Time
Noon
Noon
Noon
Noon
Noon
Noon
Noon
Date
Feb.
10
11
12
13
14
15
16
DATE AND TIME

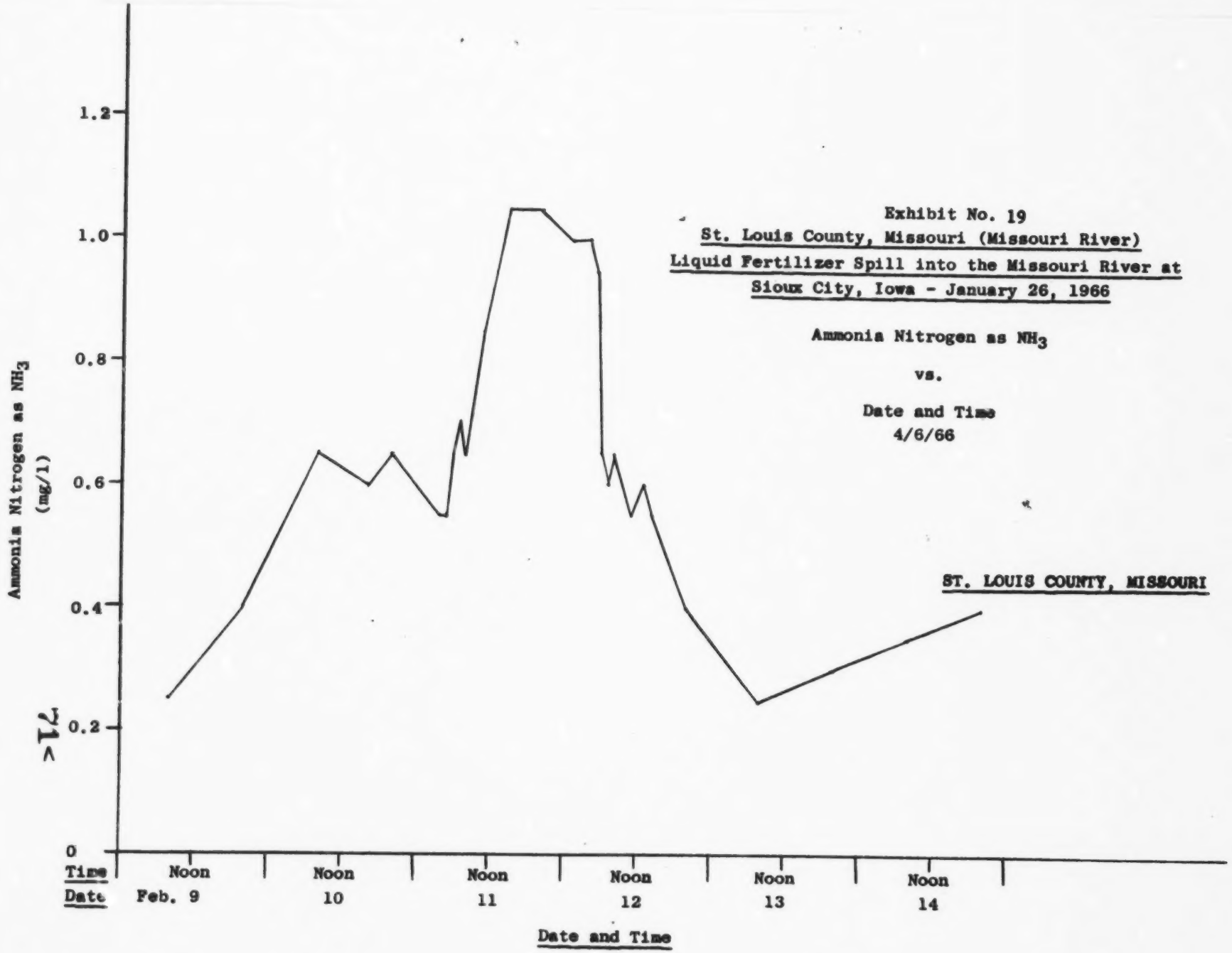


Exhibit No. 19
St. Louis County, Missouri (Missouri River)
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966
Ammonia Nitrogen as NH3
vs.
Date and Time
4/6/66
ST. LOUIS COUNTY, MISSOURI
Ammonia Nitrogen as NH3 (mg/l)
1.2
1.0
0.8
0.6
0.4
0.2
0
Time
Date
Noon Feb. 9
Noon 10
Noon 11
Noon 12
Noon 13
Noon 14
Date and Time

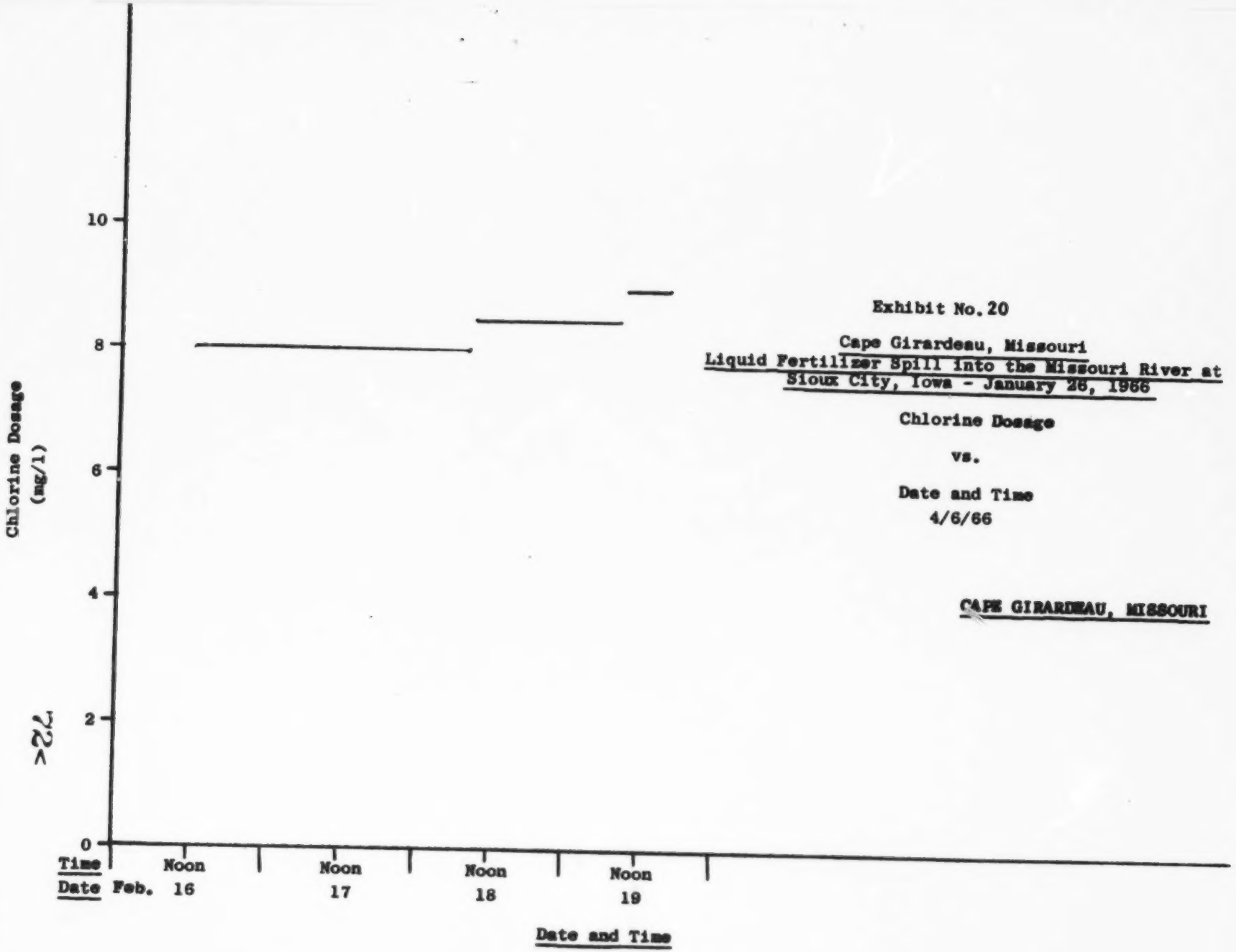


Exhibit No. 20

Cape Girardeau, Missouri
Liquid Fertilizer Spill into the Missouri River at Sioux City, Iowa - January 26, 1966

Chlorine Dosage

vs.

Date and Time
4/6/66

CAPE GIRARDEAU, MISSOURI

BREAK-POINT CHLORINATION

Exhibit No. 21 illustrates break-point chlorination. This involves the addition of at least a sufficient amount of chlorine to water to produce a minimum chlorine residual after first satisfying the chlorine demand. If organic material or ammonium compounds are present, the rate at which the chlorine residual reacts with increasing chlorine dosage is progressively less than expected, and the dosage-residual curve drops after reaching a maximum as at the "hump" in Exhibit No. 21, and the residual drops suddenly and decidedly even though the dosage is increased. Continued increase in chlorine dosage decreases the residual finally to a minimum value, after which the residual will rise in step with chlorine dosage.

This minimum is termed the "break point" because of its prominence in the curve and the changed character in the taste and appearance of the water. Break-point chlorination consists of feeding sufficient chlorine to exceed the break point. When smaller quantities of chlorine are used, the treatment is termed "marginal chlorination." Many tastes, odors and colors resulting from algae, domestic pollution and industrial wastes are completely destroyed when chlorine is fed in break-point quantity. If chlorine is added below the dosage at the hump, tastes and odors may be aggravated. From this hump on to the break point, the taste or odor will lessen. Beyond the break point tastes and odors are usually minimal. The rate of the break-point reaction is strongly dependent on pH. A maximum rate occurs between pH 7 and 8.

Advantages of chlorination to and even beyond the break point to obtain free available chlorine residuals are that most tastes and odors normal to water are destroyed and more rapid and effective disinfection is insured.

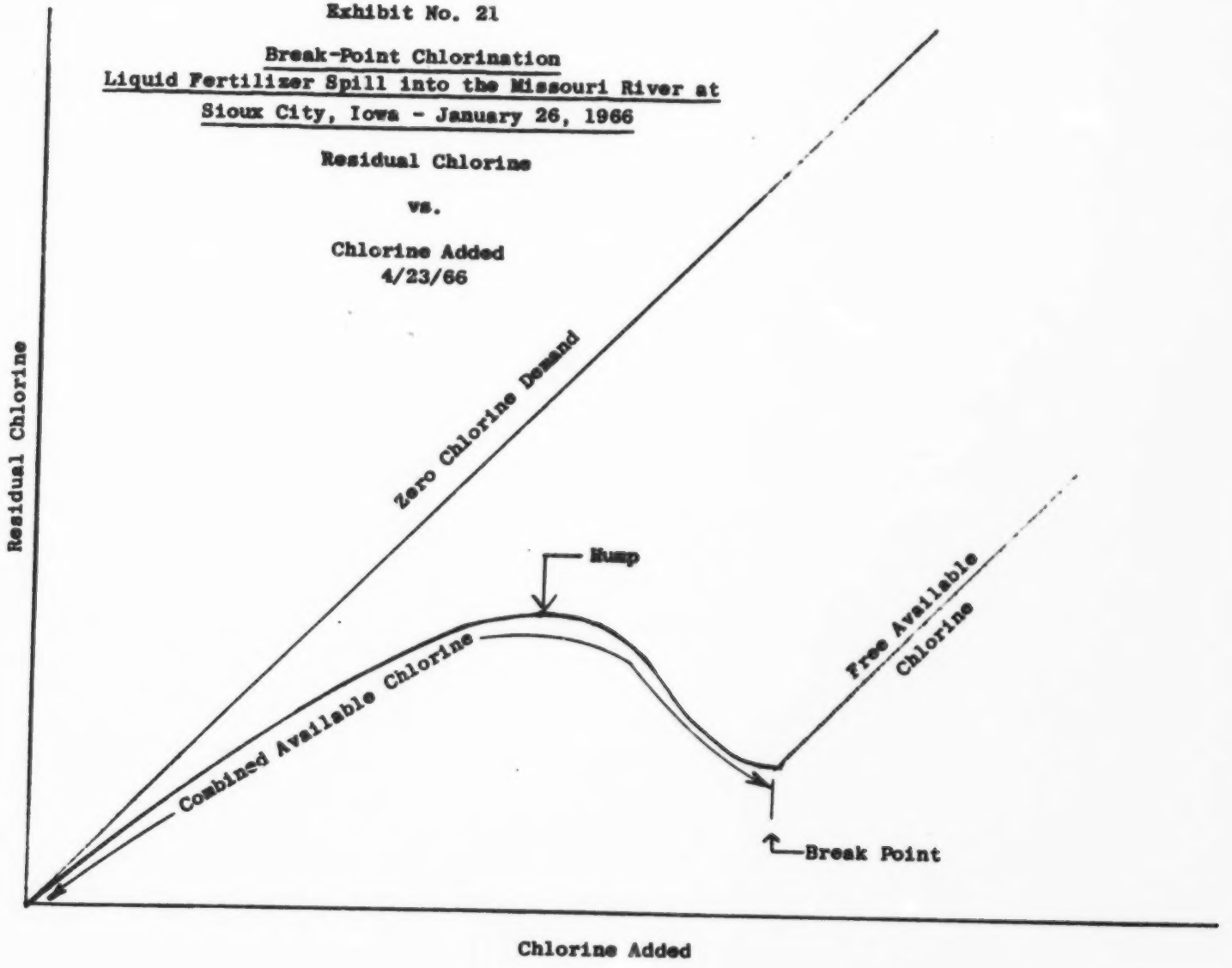
Exhibit No. 21

Break-Point Chlorination
Liquid Fertilizer Spill into the Missouri River at
Sioux City, Iowa - January 26, 1966

Residual Chlorine

vs.

Chlorine Added
4/23/66



CORPS OF ENGINEERS

U. S. ARMY

MRRED-RH

7 JUNE 1966 RCE

TIME OF WATER TRAVEL INDICATIONS BY DATA RELATED TO LIQUID FERTILIZER SPILL INTO MISSOURI RIVER AT SIOUX CITY, IOWA
JANUARY 26 - FEBRUARY 19, 1966

Stage
Discharge in 1,000 cfs
Ice Notes

WATER PLANT MILE / STATION NAME / GAGE MILE	STAGE OR DISCH	JANUARY 26	27	28	29	30	31	FEBRUARY 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
WP 730.5		X ⊡																								
SIOUX CITY		0.5	0.4	0.7	0.7	-0.6	-1.3	0.1	0.8	1.0	1.0	1.2	1.5	1.8	1.9		2.9	2.8	2.0	2.0	2.0	1.5	0.9		0.5	0.8
GS 732.3		17.0	17.0	17.0	17.0	19.0	10.0	13.0	16.0	16.0	16.0	15.0	15.5	16.0	16.0		22.0	28.0	24.0	24.0	24.0	20.0	18.0		17.0	17.0
		s	s	s	s			s	s	s	gbf				f	s	s	No ice	No ice			s	s		s	
DECATUR		32.1	32.2	32.2	32.1	31.1	31.0	30.9	39.6	40.1	40.4	40.7	41.0	41.8	41.3	38.5										
GS 690.9		80%	90%	s	s	80%	c s below	c	c	c	c	c	c	c	c	s										
WP 626.2		3.5	3.6	3.2	3.5	3.9	6.7	7.6	8.0	9.1	10.0	10.4	10.5	10.1	10.0	8.4	10.4	8.7	7.8	6.5	6.9	6.5	5.8	4.8	4.1	4.2
OMAHA		18.0	18.0	18.0	18.0	18.0	15.0	11.0	13.5	16.0	16.0	12.5	12.5	13.0	14.0	40.0	55.0	45.0	40.0	33.0	35.0	32.0	29.0	23.0	20.0	18.0
GS 615.9		90%	95%					c	c	c	c	c	c	c	No ice		10%				50%	25%	50%	70%	20%	
			X ⊡	●			⊙																			
PLATTSMOUTH		40.5	40.7	40.6	40.5	43.1	43.7	44.0	44.6	44.6	44.9	48.2	48.1	48.4	49.1	45.8										
GS 590.6		90%	70%	70%	80%	c	c	c	c	c	c	c	c	c	c	s										
NEBRASKA CITY		4.8	4.9	5.0	5.1	7.1	7.1	7.2	7.8	8.8	10.0	11.1	11.7	12.1	12.4	9.6	13.2									
GS 561.9		21.0	21.0	20.0	20.0	20.0	18.0	12.0	13.0	9.0	11.0	14.0	15.0	16.0	17.0	45.0	70.0									
		80%	80%	90%	90%	c	c	c	c	c	c	c	c	c	Ice moving	50%	30%									
BROWNVILLE		79.3	79.4	79.8	neg	neg	84.0	83.5	83.5	84.3	85.1	ma-	neg	a.? 9	88.1	86.2										
GS 535.3		80%	s	s		c	c	c	c	c	c	c	c	c	c	s										
NULO		4.6	4.5	4.4	10.1	9.8	9.8	9.8	9.5	9.6	10.3	12.4	12.4	13.2	13.6	10.5	10.4	12.6	12.0	10.1	9.4	8.8	8.2	7.3	6.5	5.9
WP 498.1		21.0	21.0	21.0	19.0	18.0	18.0		14.0	17.0	15.0	14.0	14.0	17.0	17.0	55.0	55.0	70.0	80.0	57.0	50.0	54.0	47.0	38.0	35.0	30.0
		70%	70%	90%	c	c	c	c	c	c	c	c	c	c	c	15%	20%	20%				20%	20%	50%	40%	50%
WP 452.2		10.3	6.7	7.4	5.5	5.4	4.9	5.1	5.2	4.8	4.9	5.1	5.9	6.8	7.8	15.8	11.9	14.1	13.8	12.1	10.8	10.4	10.0	9.2	8.4	7.7
ST. JOSEPH							■X					●			⊡	⊙										
GS 448.7		40.0	21.5	22.0	15.0	14.0	12.0	17.0	12.0	12.0	9.5	10.0	12.0	14.0	18.0	65.0	55.0	70.0	80.0	63.0	60.0	55.0	50.0	43.0	38.0	33.0
		70%	65%	70%	d	d	d	d	d	d	d	d	d	d	50% abv	75%	50%	5%		No ice				20%	10%	
WP 423.0		9.4	9.4	9.5	11.8	11.3	11.9	12.7	12.7	12.7	12.8	13.0	13.9	15.0	16.1	19.3	14.6	16.8	16.6	15.1	13.4	13.0	12.4	11.5	10.4	9.7
ATCHISON								X			⊡	●					⊙									
GS 422.5		90%	70%	80%	h a	h a	h a	h a	h a	h a	h a	h a	h a	h a	Ice out at 6pm	25%	20%	40%	T	No ice						
WP 396.8		5.7	5.7	5.4	3.0	2.6	2.7	3.7	4.7	5.3	5.6	5.9	5.6	6.2	6.7	14.0	10.4	12.7	12.7	11.4	9.7	9.3	8.8	8.0	7.6	6.6
LEAVENWORTH						d																				
GS 396.7		90%	90%	90%	70%	10%	10%	d 10%	X d	d	d	d	d	d	●	⊙							20%	30%		40%
WP 373.7		4.9	4.9	4.9	4.8	4.5	4.6	4.6	4.7	5.1	5.0	5.8	5.3	5.9	6.5	11.6	9.8	11.2	9.1	10.7	9.0	8.6	8.0	7.5	6.5	6.0
KANSAS CITY, KS.		s	s	s+	c	c	c	c	c	c	c	c	c	c	c	s+f	f	f	f						s	s
KANSAS CITY, MO.										d		⊡●			⊙											
WP 370.5					c	c	c	c	c	c	c	c	c	c	c											
KANSAS CITY, MO.		1.0	3.7	1.6	-2.0	-1.7	-1.7	-1.3	-1.1	-0.7	-0.4	-0.5	-0.1	0.4	1.0	8.0	7.1	8.7	9.4	8.4	6.9	6.6	6.3	6.0	5.4	4.8
GS 366.1		21.0	32.0	24.5	9.0	10.0	10.0	8.5	9.5	12.0	11.5	12.0	13.0	15.0	16.0	60.0	52.0	68.0	80.0	63.0	65.0	64.0	61.0	56.0	50.0	45.0
		90%	90%	70%	None									No ice		s +	15%	15%			No ice		No ice	10%	No ice	
WP 318.0		8.0	9.0	9.5	12.2	10.0	11.0	11.1	11.1	12.0	12.5	12.9	13.1	13.4	14.3	13.5	14.6	14.7	15.7	15.3	13.7	12.9	12.6	12.3	11.6	11.2
LEXINGTON		21.0	28.0	26.0	13.0	11.0	10.0	8.5	10.0	12.0	12.0	12.0	13.0	15.0	16.0	50.0	65.0	65.0	85.0	80.0	72.0	65.0	62.0	57.0	50.0	47.0
MB 317.3		75%	90%	90%	c	c	c	c	c	c	c	c	c	c	c	5%	50%	30%	10%	-				T		
WAVERLY																										
GS 291.6		24.0	27.0	33.0	16.0	12.0	11.0	9.0	10.0	12.0	12.0	12.0	13.0	15.0	16.0	50.0	70.0	60.0	85.0	80.0	75.0	65.0	63.0	58.0	52.0	47.0
		80%	80%	75%	c	c	90%	c	90%	c	c	c	c	90%	c	90%	s		20%					No ice		
WP 227.0		8.6	14.6	13.8	13.0	12.9	12.7	12.5	10.9	11.1	11.1	11.4	11.8	12.2	12.6	13.0	14.9	15.5	17.2	17.3	16.0	14.7	14.1	13.8	13.2	12.4
GLASGOW		25.0	40.0	35.0	16.0	16.0	15.0	9.5	10.0	11.0	11.0	12.0	13.0	14.0	15.0	17.0	80.0	75.5	90.0	92.0	77.0	70.0	64.0	59.0	53.0	49.0
CR 226.3		75%	c	c	c	c	c	c	c	c	c	c	c	c	c	c	100%	20%	20%	5 %	No ice			No ice		
														X						⊙						
WP 197.0		5.2	2.2	2.3	1.6	1.6	2.0	1.5	1.5	0.4	0.5	0.7	1.5	1.5	2.0	2.9	13.1	12.7	13.3	13.6	12.8	11.5	10.9	10.4	10.0	9.2
BOONVILLE		26.0	13.0	13.0	13.0	13.0	15.0	10.0	10.0	10.0	10.0	11.0	14.0	14.0	15.0	X 17.0	85.0	82.0	88.0	■● 92.0	83.0	70.0	⊡ 65.0	59.0	55.0	⊙ 49.0
GS 197.1		s	d	30%	d 20%	d s	d 10%	d	d 20%	d 5%	d 30%	d 10%	d	d	d	d	s	s	s	s	s					
WP 145.0		8.1	6.5	10.2	10.2	8.1	8.0	9.2	8.8	7.5	7.2	7.5	7.5	7.6	9.0	9.8	15.1	14.4	14.0	14.3	13.5	12.2	11.3	11.0	10.7	10.1
JEFFERSON CITY		c	c	90%	c	c	c	c	90%	c	80%	c	c	c	c	c										
MB 143.9																		X			⊡●			⊙		
HERMANN		5.7	1.4	3.0	neg	neg	2.3	neg	neg	3.1	2.2	2.7	2.3	1.9	2.1	3.1	16.2	13.0	17.8	17.9	18.0	17.3	14.7	13.3	12.2	11.4
GS 97.9		34.0	13.0	19.0			16.0			19.0	15.0	18.0	16.0	14.0	15.5	20.0	115.0	140.0	138.0	139.0	140.0	130.0	97.0	92.0	80.0	73.0
		s	d	d	d	d	d s	d			d s	90%	d	d	d	d	d									
MB 37.1																										
ST. LOUIS STAGES (Howard Sand)		16.2	15.4	15.7	15.2	15.4	14.8	14.2	14.0	14.3	14.7	14.2	14.2	14.1	13.7	13.8	18.1	29.1	29.2	29.0	29.5	28.7	27.2	25.2	24.1	23.3
MP (W.Q. DATA) ST. LOUIS CO.																X			⊡●		⊙					

LEGEND

ICE NOTES
a Obstructed by rough ice
c Frozen over
d Ice gorge above gage
f Shore ice
g Floating ice
h Pool stage

FERTILIZER SPILL
X Leading edge
⊡ Peak
⊙ Trailing edge
● Center of mass
■ Secondary peak

Miscellaneous
Gage data furnished by the Agency underlined

EXHIBIT NUMBER 22